“DESIGN AND OPTIMIZATION OF MULTI SLOT MICROSTRIP PATCH ANTENNA FOR WIRELESS APPLICATIONS”

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ABSTRACT

The objective of this thesis is to design and optimize the performance of microstrip antenna to efficiently operate at 4.1GHz and 3.5GHz frequencies for wireless applications. In this work, rectangular microstrip patch antennas are designed without slots and with multiple slots with the goal to achieve desired results. This paper presents the designs of compact size, cost-efficient, narrow band microstrip antennas using FR-4 substrate with dimensions calculated based on the resonant frequencies. Three different antennas are designed for each of the resonant frequencies. Several attempts are made to optimize the dimensions of the antenna parameters to improve the minimum return loss achieved, bandwidth, radiation pattern, directivity and gain; which are simulated using CST Microwave Studio simulation software. The proposed antenna for 4.1GHz resonated at a return loss of -21.8dB, giving a bandwidth of 177.3MHz which is 4.324% at -10dB, VSWR of 1.177, 5.946dBi directivity and 2.98dB gain. For 3.5GHz the proposed antenna achieved a minimum return loss of -49.42dB, bandwidth obtained about 151.7MHz which is 4.33% at -10dB, VSWR of 1.006, 5.95dBi directivity and 3.13dB gain.

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Firstly, we would like to thank the Almighty Allah for giving us the confidence, ability and strength to complete the thesis and making this study a success. We would like to express our deepest gratitude to our thesis supervisor, Ms. Iffat Alam (Senior Lecturer Department of Electronics and Communications Engineering, East West University) under whose guidance we had the privilege to complete this thesis. We wish to express our deepest gratitude towards her for providing individual guidance and support throughout the thesis work. With the help of her continuous guidance and knowledge, it was possible to complete the task without any problem. We highly appreciate her motivation and encouragement during the work on our project. Our greatest thanks to all who wished us success especially Dr. M. Mofazzal Hossain and Dr. Mohammed Moseeur Rahman. Also we would like to give thanks our senior brother Mir Md. Saym for helping us. We want to express our gratitude to the faculty members who have helped us with their valuable knowledge and solid information. Also, the staffs of the Department of ECE were also cooperative at the time of need. We would like to extend our gratitude to all those person who directly or indirectly helped us in the process and contributed towards this work. The project was produced with the help and commitment of each of our group members. Thus, we take accept this opportunity to thank every single one of us.

DECLARATION

We hereby declare that we are the sole authors of this work titled, “Design and Optimization of Multi Slot Microstrip Patch Antenna for Wireless Applications”. This declaration is to clarify that all the work and findings of this thesis are original; except for the contents that have been acknowledged in the references. We further authorize, East West University to use this thesis report only for the purposes of research.

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Abbreviations

VSWR ……………………… Voltage standing wave ratio

RL…………………………… Return loss

CST ……………………...….. Computer simulation technology

WLAN ……………………… Wireless local area network

FR4…….…………………….. Flame resistant four

S Parameters………………… Scattering Parameters

WiMAX……………………... Worldwide Interoperability for Microwave Access

Chapter 1 : Introduction

1.1 Thesis Approach

In modern communication system Wireless communication is more popular communication system and WiMAX technology enables ubiquitous delivery of wireless broadband service for fixed and/or mobile users. That's why it's becoming rapidly use of radio/wireless technology creates greater demand for small, efficient, and low-cost antennas in a range of telecommunications and wireless local area network (WLAN) applications, as well as worldwide interoperability for microwave access (WiMAX), satellite communications (satcom), and spacecraft. Microstrip patch antennas became well received in wireless communications systems due to their ease of creation and viability in those systems. With the expanding number of remote applications, an antenna for wireless communications must also operate across various frequencies, so that it can be used for a number of various applications simultaneously. Thus, a low profile, wide bandwidth, high directivity antennas are in great demand for commercial area The main drawback of microstrip antennas is their narrow bandwidth. In this work we have directed an examination to structure of a micro strip patch antenna with slots in the rectangular patch to have good performance. Our requirement was to design antenna and performance analysis. We have used FR-04 as substrate, inset feed line, copper as patch and ground. Also we have done complex slot, simple slot and try to reduce the size of antenna. The outlines appeared underneath 'Fig. 2.4' show how the model of the patch antenna will resemble, where L represent to the length of the patch, W is the width of the patch and 'h' is the thickness of the substrate, height of the patch 't' and ε_r is permittivity [1],[2].

1.2 Thesis Overview

This outline gives a knowledge of what will be going on entire paper and in every individual part.

Chapter 1: The first chapter contains the overview and introduction of each chapter it describes the need of compact micro strip patch antenna and why we have designed this. The brief introduction of research paper are given for the various antenna design based on wireless application.

Chapter 2: This chapter gives the introduction to the antenna and describe the different type of antenna.

Chapter 3: In this chapter discussed input impedance and the basic theory for analysis the patch antenna parameters as like return loss, directivity, gain, fir field radiation, bandwidth, beam width, efficiency, etc.

Chapter 4: In this chapter they will be a theoretical aspect about microstrip patch antenna which include designing and feeding techniques. There's a comparison of plain and slotted microstrip patch antenna. Also describe the formula of patch antenna and describe the different effect.

Chapter 5: This part contains the short depiction of CST Microwave Studio which incorporate general highlights, structure modification and solver technology. It also contains the design procedure with proper data, table and diagram of the patch antenna. We also broadly analyses every part of the simulation in this chapter and compare with the theoretical part. Also compare the antenna.

Chapter 6: This is the last chapter of the report and it contain short summery about our thesis. Also discuss aims on the project objectives and the areas which requires modification and also mentions limitations within the project. We've mentioned the data and tools involved in our work and why our proposed antenna is a convenient one. We've also mentioned some point as a future work purpose.

Chapter 2 : Antenna

2.1 Introduction to Antenna

An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves." The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines the antenna or aerial as "a means for radiating or receiving radio waves." In other words the antenna is the transitional Construction between free-space and a guiding device, as shown in Figure 2.1. The guiding device or transmission line may take the form of a coaxial line or a hollow tube (Waveguide), and it is used to transport electromagnetic energy from the transmitting Source to the antenna, or from the antenna to the receiver. In the former case, we have a transmitting antenna and in the latter a receiving antenna.

An antenna is the transitional structure between free space and a directing gadget. The directing gadget or transmission line may take the shape of a coaxial line or a waveguide, and it is utilized to transport electromagnetic vitality from the transmitting source to the antenna, or from the antenna to the recipient.

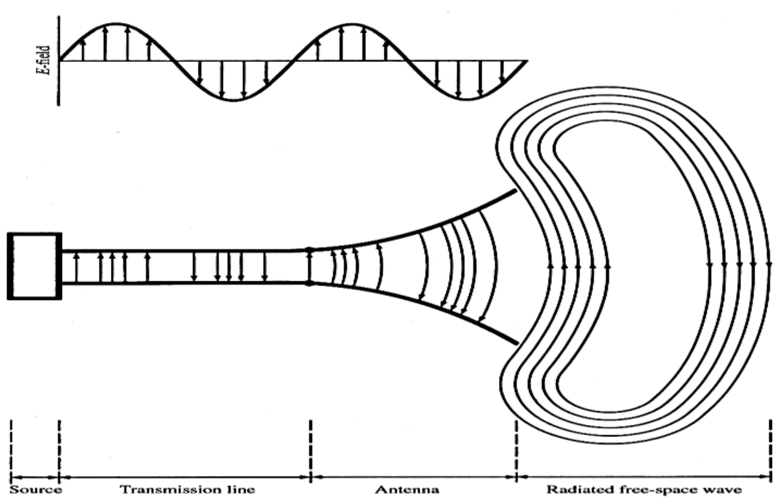


Figure 2.1: Antenna as a transition device [3].

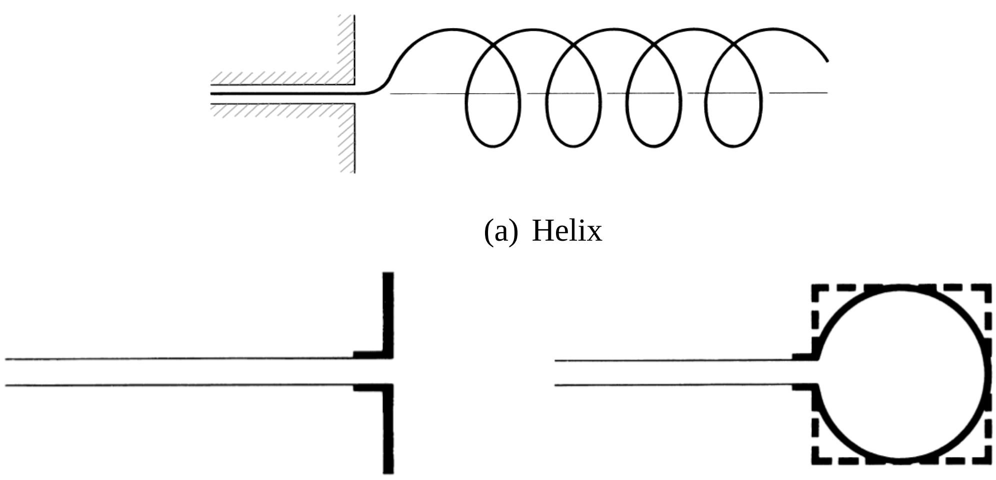
Antennas have an association of metal conductors with an electrical connection to receivers or transmitters. Modern is pressured thru these conductors through radio transmitters to create alternating magnetic fields. Those fields induce voltage on the antenna terminals, which are connected to the receiver enter. In the some distance field, the oscillating magnetic subject is coupled with a similar oscillating electric powered field, which defines electromagnetic waves capable of propagating the sign for lengthy distances [4].

2.2 Types of Antennas

There are different antenna we are going presently present and briefly examine a few shapes of the various antenna types in arrange to urge a look as to what will be experienced within the leftover portion of the proposal.

2.2.1 Wire Antennas

Wire antennas are recognizable to the layman since they are seen essentially all over on automobiles, buildings, ships, flying machine, shuttle, and so on. There are different shapes of wire antennas such as a straight wire (dipole), circle, and helix which are appeared in Figure 2.2. Circle antennas require not as it were be circular. They may take the frame of a rectangle, square, oval, or any other arrangement. The circular circle is the foremost common since of its effortlessness in development [3].



(a) Helix

(b) Dipole

(c) Circular loop

Figure 2.2: Wire antenna configurations [3].

2.2.2 Aperture Antennas

Gap antennas may be additional commonplace to the layman these days than within the past due to the developing request for more state-of-the-art styles of antennas and the usage of better frequencies. A couple of styles of gap antennas are appeared in figure 2.3. Antennas of this kind are exceptionally useful for plane and shuttle programs, since they can be exceptionally promptly flush-installed at the pores and skin of the plane or shuttle. In expansion, they can be covered with a dielectric fabric to ensure them from hazardous circumstances of the environment [3].

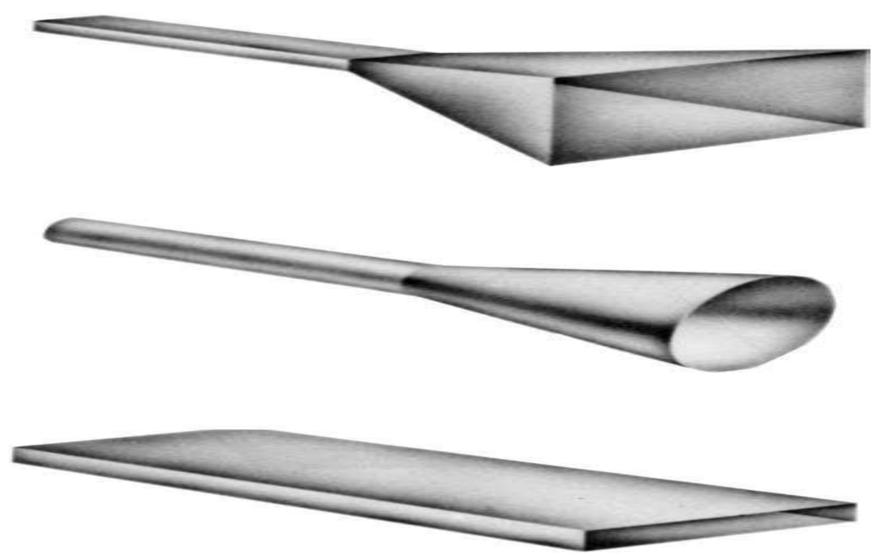
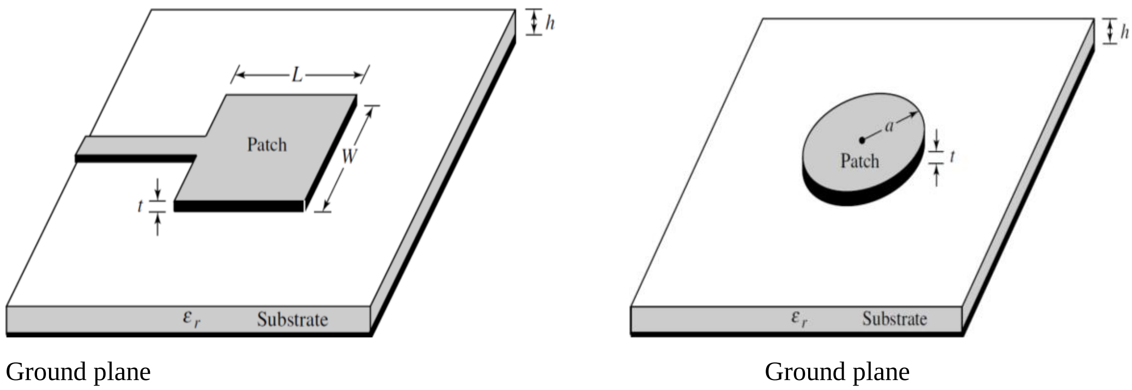


Figure 2.3: Aperture antenna configurations [3].

2.2.3 Microstrip Antennas

Microstrip antennas got to be exceptionally prevalent within the 1970s essentially for space borne applications. Nowadays they are utilized for government and commercial applications. These antennas comprise of a metallic patch on a grounded substrate. The metallic patch can take numerous distinctive arrangements, as appeared in Figure (4.3). Be that as it may, the rectangular and circular patches, showing Figure 2.4, are the foremost prevalent since of ease of examination and manufacture, and their alluring radiation characteristics, particularly low cross-polarization radiation. The microstrip antennas are low profile, comparable to planar and nonplanar surfaces, basic and cheap to manufacture utilizing present day printed-circuit innovation, mechanically vigorous when mounted on unbending surfaces, consistent with MMIC plans, and exceptionally flexible in terms of resounding recurrence, polarization, design, and impedance. These antennas can be mounted on the surface of high-performance airplane, shuttle, satellites, rockets, cars, and indeed handheld portable phones [3].

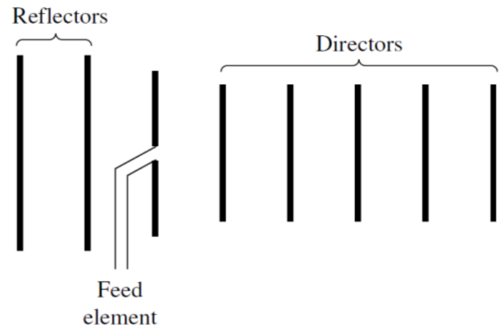


(a) Ractangular (b) Circular

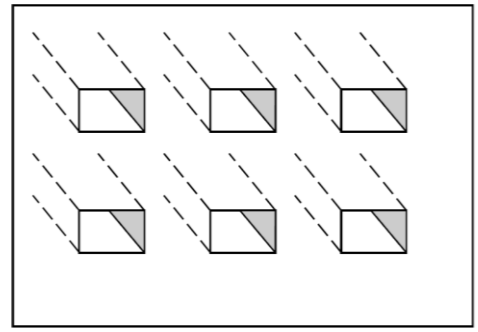
Figure 2.4: Rectangular and circular microstrip (patch) antennas [3].

2.2.4 Array Antennas

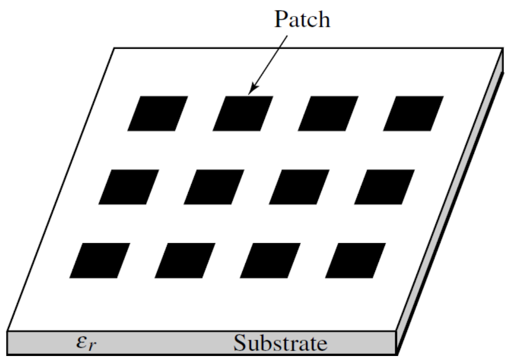
Numerous applications require radiation characteristics that will not be achievable by a single component. It may, be that as it may, be conceivable that a total of transmitting components in an electrical and geometrical arrangement (a cluster) will result within the crave radiation characteristics. The course of action of the cluster may be such that the radiation from the components includes up to deliver a radiation most extreme in a specific heading or bearings, least in others, or something else as craved. Ordinary illustrations of clusters are appearing Figure 2.5. More often than not the term cluster is saved for a course of action in which the person radiators are partitioned as appeared in Figures 2.5(a–c). In any case the same term is additionally utilized to depict a get together of radiators mounted on a ceaseless structure, appearing Figure 2.5(d) [3].



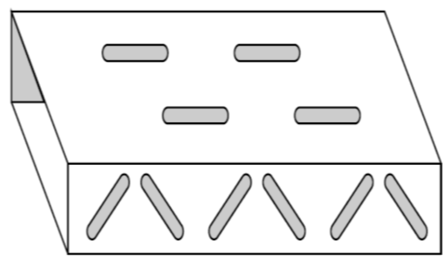
(a) Yagi-Uda array



(b) Aperture array



(c) Microstrip patch array

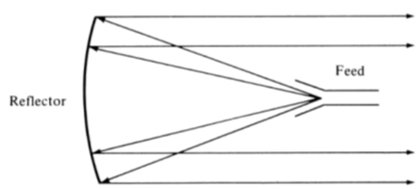


(d) Slotted-waveguide array

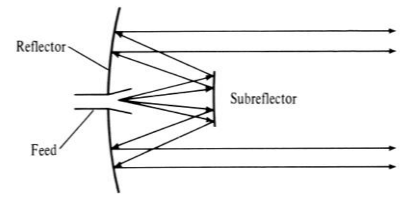
Figure 2.5: Typical wire, aperture, and microstrip array configurations [3].

2.2.5 Reflector Antennas

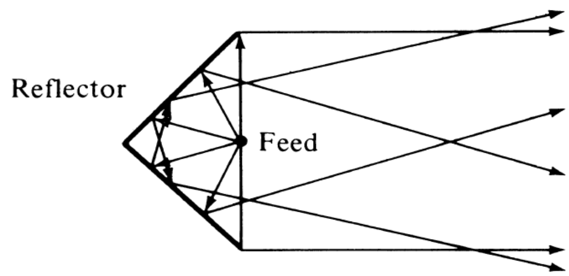
The victory within the investigation of outer space has brought about within the advancement of antennas hypothesis. Communicate over awesome separations, modern shapes of antennas had to be utilized in arrange to transmit and get signals that had to travel millions of miles. An awfully common antenna shape for such an application could be an allegorical reflector appeared in Figures 2.6(a) and (b).Antennas of this sort have been built with distances across as huge as 305 m. Such expansive measurements are required to realize the tall pick up required to transmit or get signals after millions of miles of travel. Another shape of a reflector, in spite of the fact that not as common as the allegorical, is the corner reflector, appeared in Figure 2.5(c) [3].



(a) Parabolic reflector with front feed



(b) Parabolic reflector with cassegrain gain

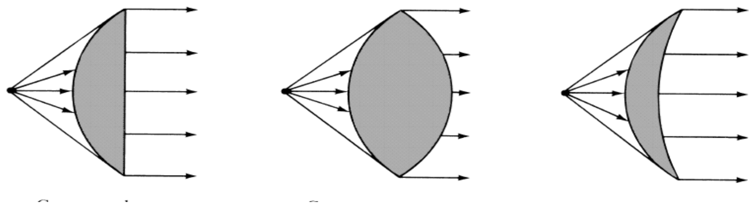


(c) Corner reflector

Figure 2.6: Typical reflector configurations [3].

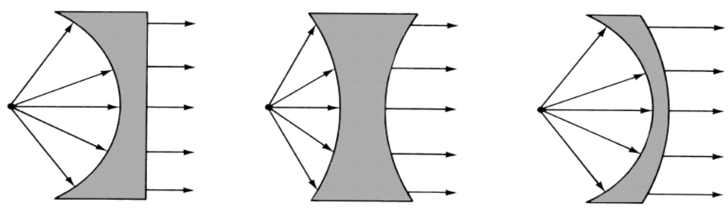
2.2.6 Lens Antennas

Lenses are fundamentally utilized to collimate occurrence unique vitality to avoid it from spreading in undesired bearings. By legitimately forming the geometrical setup choosing the suitable fabric of the focal points, they can change different shapes of unique vitality into plane waves. They can be utilized in most of the same applications as are the illustrative reflectors, particularly at higher frequencies. Their measurements and weight ended up exceedingly huge at lower frequencies. Focal point antennas are classified agreeing to the fabric from which they are developed, or agreeing to their geometrical shape. A few shapes are appearing Figure 2.7. In outline, a perfect antenna is one that will transmit all the control conveyed to it from transmitter in a craved heading or headings. In hone, in any case, such perfect exhibitions cannot be accomplished but may be closely drawn nearer. Different sorts of antennas are accessible and each sort can take diverse shapes in arrange to realize the specified radiation characteristics for the specific application. All through the book, the radiation characteristics of most of these radio wires are talked about in detail. [3]



Convex-plane　　Convex-Convex　　Concave-Convex

(a)Lens antenas with index of refraction n>1



Concave-plane　　Concave-Concave　　Concave-Convex

(b)Lens antenas with index of refraction n>1

Figure 2.7: Typical lens antenna configurations. (SOURCE: L. V. Blake, *Antennas*, Wiley, New York, 1966).

Chapter 3 : Antenna Theories

To define the performance of an antenna, we need to know some parameters of antennas. In this chapter we discus some parameter of antenna which are interrelated to specified for complete description of the antenna performance.

3.1 Input Impedance

Input impedance is defined as the impedance displayed by a receiving antenna at its terminals or the proportion of the voltage to current at a combine of terminals or the proportion of the fitting components of the electric to attractive fields at a point. [3]

In fig 2.2, R_A =,R_L+, R_r is the real part and X_A is the imaginary part. The resistive part relates to the power dissipation, while the imaginary (reactive) part relates to power stored in the near field of the antenna.

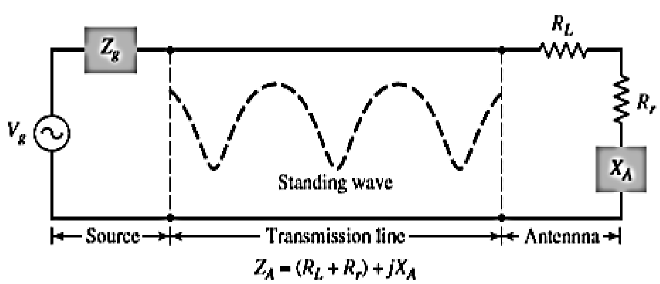


Figure 3.1: Transmission-line Thevenin equivalent of antenna in transmitting mode [3].

Input impedance is imperative to decide greatest control exchange between transmission line and the antenna. This exchange happens legitimately as it were when input impedance of antenna and input impedance of the transmission line matches. In case they don't coordinate, reflected wave will be produced at the radio wire terminal and travel back towards the vitality source.

3.2 Radiation Pattern

Radiation design is defined as a scientific work or a graphical representation of the radiation properties of the radio wire as a work of space arranges. Radiation properties incorporate control flux thickness, radiation escalated, field quality, directivity, stage or polarization. [3]

If the antenna had a 100% radiation efficiency, all directivity would be converted to gain. Typical half wave patches have efficiencies well above 90%.

The radiation designs can be field designs or control designs. The field designs are plotted as a work of electric and attractive areas. They are plotted on logarithmic scale. The control designs are plotted as a work of square of the size of electric and attractive areas. They are plotted on logarithmic or commonly on dB scale.The radiation pattern is a three-dimensional figure and represented in spherical coordinates (r, θ, Φ) assuming its origin at the center of spherical coordinate system. Two-dimensional design can be gotten from three-dimensional design by separating it into level and vertical planes. These resultant designs are known as Level design and Vertical design separately [4].

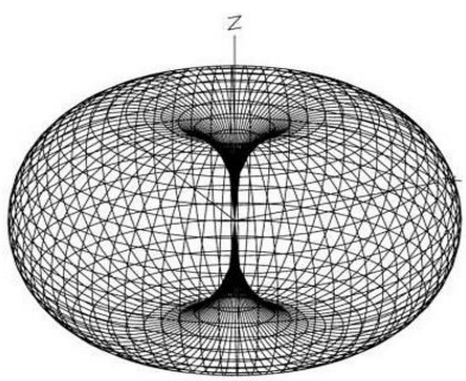


Figure 3.2: Radiation pattern in 3D.

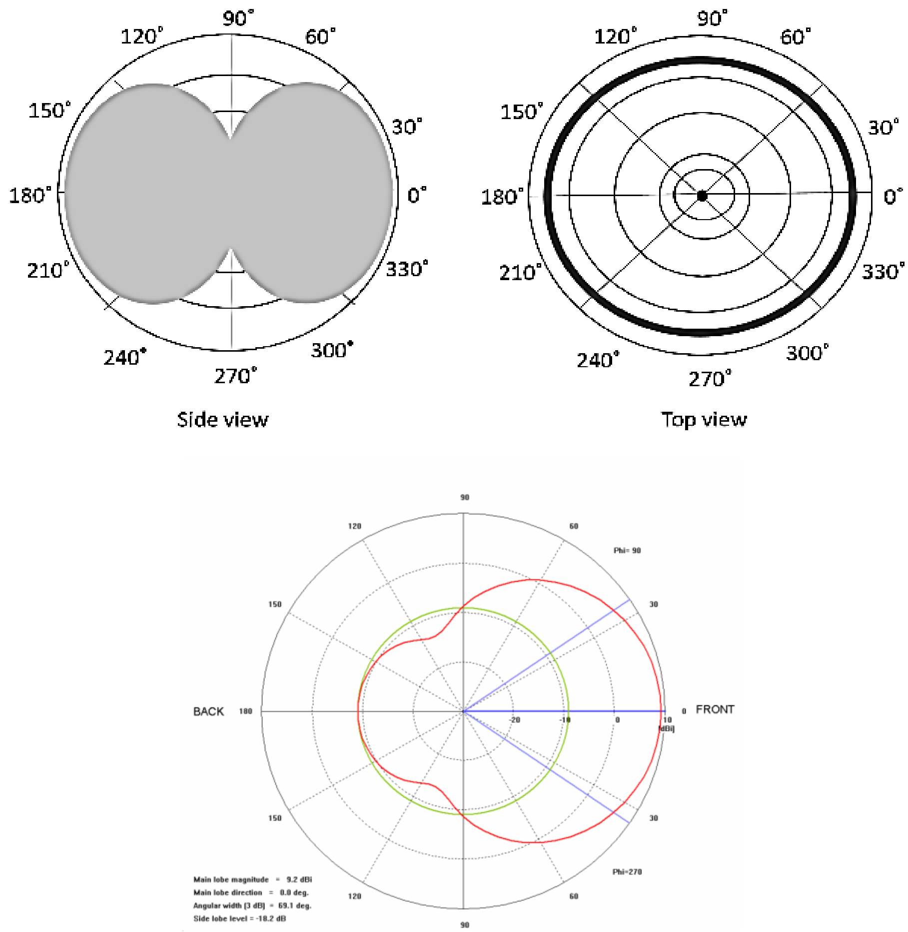
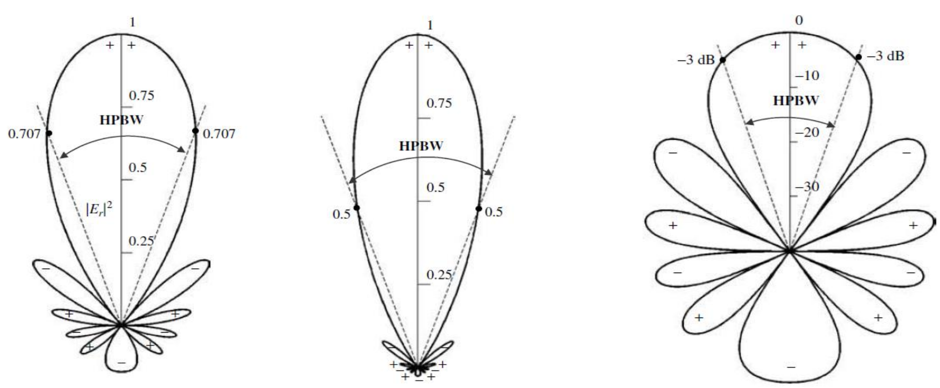


Figure 3.3: Typical radiation pattern of a simple square patch [3].



(a) Field pattern (in linear scale); (b) Power pattern (in linear scale); (c) Power pattern (in dB)

Figure 3.4: Two-dimensional normalized field pattern (linear scale), power pattern (linear scale), and power pattern (in dB) of a 10-element linear array with a spacing of d = 0.25λ [3].

3.3 Field Regions

Antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraunhofer) regions as shown in Figure 3.5. The boundaries separating these regions are not unique, although various criteria have been established and are commonly used to identify the regions.

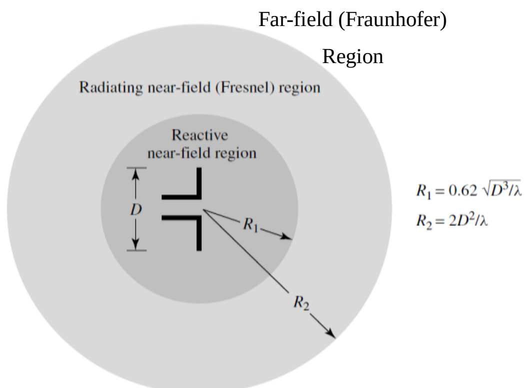


Figure 3.5: Field regions of an antenna [3].

The space surrounding an antenna is usually subdivided into three regions,

1. **Reactive Near Field Region:** This field is within the quick region of the receiving wire. In this locale, the areas are predominately receptive areas, which implies the E- and H- areas are out of stage by 90 degrees to each other. The outer boundary of this region is commonly taken to exist at a distance $\boldsymbol{R < 0.62\sqrt{D^3/\lambda}}$ from the antenna surface.
2. **Radiating Near Field (Fresnel) Region:** This field is the locale between the receptive close and distant areas. In this locale, the receptive areas are not overwhelm; the emanating areas start to develop. Here the shape of the radiation pattern may vary appreciably with distance. Here the boundary of the region is taken as

$$\boldsymbol{0.62\sqrt{D^3/\lambda} < R < 2D^2/\lambda} \quad \textbf{(3.01)}$$

3. **Far Field (Fraunhofer) Region:** This field is the locale distant from the receiving wire, here the radiation design does not alter shape with. Too, this locale is overwhelmed by emanated areas, with the E- and H-fields orthogonal to each other and the course of engendering as with plane waves. The inner boundary is taken to be the radial distance $\boldsymbol{R < 2D^2/\lambda}$ and the outer one at infinity [5].

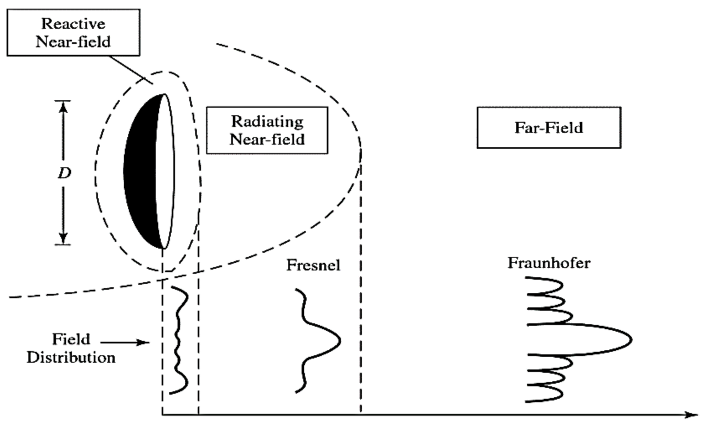


Figure 3.6: Typical changes of antenna amplitude pattern shape [3].

3.4 Radiation Intensity

Radiation concentrated is characterized as the control per unit strong point. Radiation radiated from a receiving wire which is more strongly in a specific course, demonstrates the greatest escalated of that radio wire. It could be a far-field parameter, and it can be gotten by basically duplicating the radiation thickness by the square of the remove. [3] In mathematical form it is expressed as,

$$U = r^2 W_{rad} \tag{3.02}$$

Where 'U' is the radiation intensity, 'r 'is the radial distance and $'W_{rad}'$ is the power radiated from the antenna.

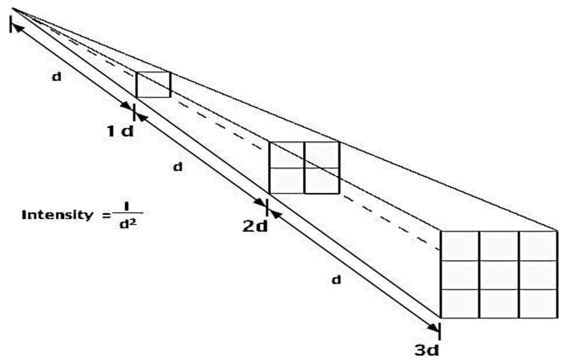


Figure 3.7: The nature of radiation [3].

3.5 Beamwidth

Beam width is the aperture angle from where most of the power is radiated. It includes a trade-off since the side flap level increments as the beamwidth diminishes and bad habit versa. It is additionally utilized to portray the capability of the receiving wire to recognize between two adjoining transmitting sources or radar target [4].

a) **Half Power Beam Width (HPBW):** It is the angular separation, in which the magnitude of the radiation pattern decreases by 50% (or -3dB) from the peak of the main beam.
b) **Full Power Beam Width (PPBW):** It is the angular span between the first pattern nulls adjacent to the main lobe

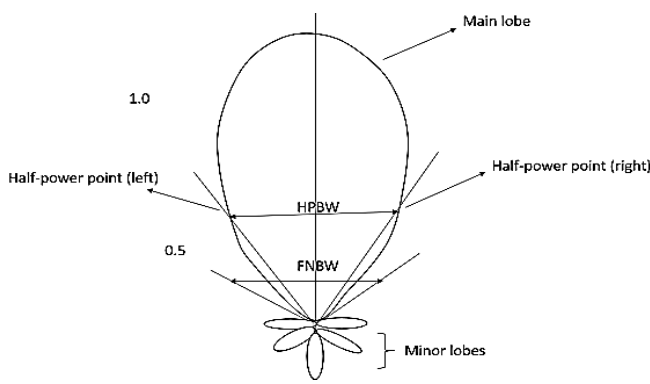


Figure 3.8: Beam width of an antenna [3].

3.6 Directivity

The proportion of most extreme radiation concentrated of the subject receiving wire to the radiation concentrated of an isotropic or reference antenna, emanating the same add up to control is called the directivity. The fractional directivity of an antenna for a given polarization is, the portion of the radiation concentrated comparing to that polarization, separated by the full radiation escalated found the middle value of overall headings. [3] The mathematical expression of directivity,

$$D = \frac{U}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \tag{3.03}$$

If that particular direction is not specified, then the direction in which maximum intensity is observed, can be taken as the directivity of that antenna.

3.7 Gain

Gain of an antenna is the ratio of the radiation intensity in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. It depicts how much control is transmitted within the course of crest radiation to that of an isotropic source. Unlike directivity, antenna gain takes the losses that occur also into account and hence focuses on the efficiency. It is usually measured in dB.

$$\mathrm{G} = 4\pi \, \frac{\text{Radiation intensity}}{\text{Total input(accepted)power}}$$

$$or, G = 4\pi \frac{U(\theta, \Phi)}{P_{in}} = \eta_e D \tag{3.04}$$

Where 'η_e' is the efficiency and 'D' is the directivity of the antenna [3].

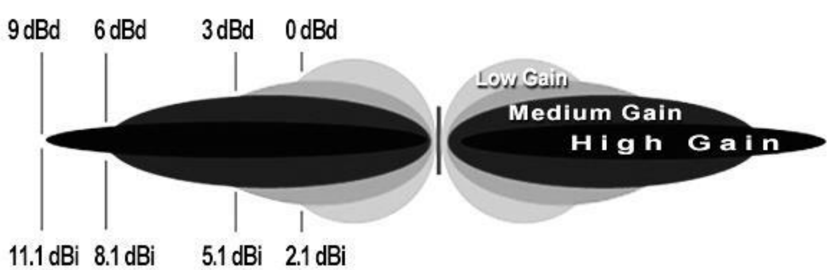


Figure 3.9: Illustration of antenna gain measurement [3].

3.8 Bandwidth

Bandwidth is band of frequencies between higher and lower frequencies indicated for a specific communication over which the antenna can appropriately emanate or get vitality. For narrowband receiving wires, the transmission capacity is communicated as a rate of the recurrence contrast (upper short lower) over the center recurrence of the transfer speed. The Percentage bandwidth is calculated to know how much frequency variation either a component or a system can handle.

$$\text{Percentage Bandwidth} = \frac{\text{Abslout Bandwidth}}{\text{Center frequency}}$$

$$\text{or, \%BW} = \frac{\mathrm{F_H - F_L}}{\mathrm{F_C}} \tag{3.05}$$

Where F_H & F_L represents higher & lower frequency.

3.9 Polarization

The polarization is the introduction of the electric field distant from the source. It portrays the time-varying heading and relative greatness of the electric field vector. Polarization for an antenna in a given course is characterized as the polarization of the E-field transmitted by the antenna. When the heading isn't expressed the polarization is taken to be the polarization within the heading of greatest pick up. The polarization of a wave transmitted by an antenna, in a indicated course, at a point within the distant field, is characterized as the polarization of the plane wave which is utilized to speak to the transmitted wave at that point. Polarization may be classified as linear, circular, elliptical, circular left hand, circular right hand, elliptical right and elliptical left hand [3].

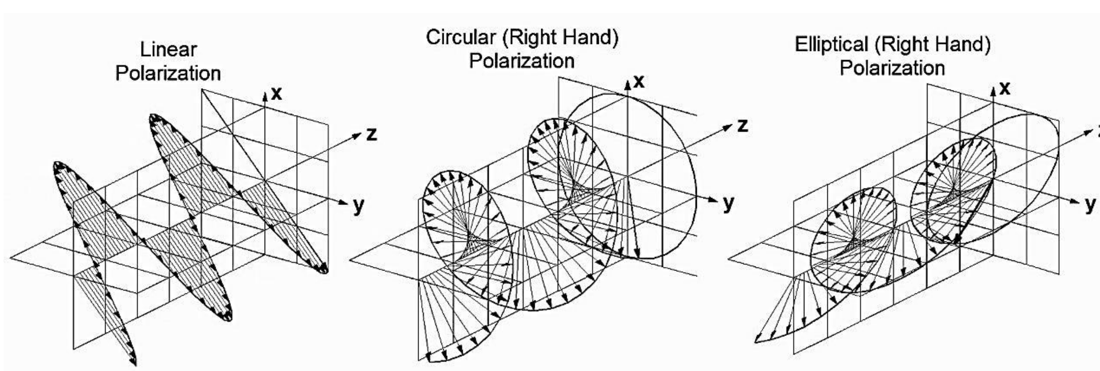


Figure 3.10: Linear, circular & Elliptical polarization [3].

3.10 Radiation Efficiency

Radiation proficiency is the proportion of the emanated control of the antenna to the input control acknowledged by the antenna. The productivity of an antenna clarifies how much an antenna is able to provide its yield viably with least misfortunes within the transmission line. It is in some cases called radiation effectiveness. One nice property of antennas is that the efficiency is the same whether we are using the antenna as a transmitting or receiving antenna [4]. The mathematical expression can be given as,

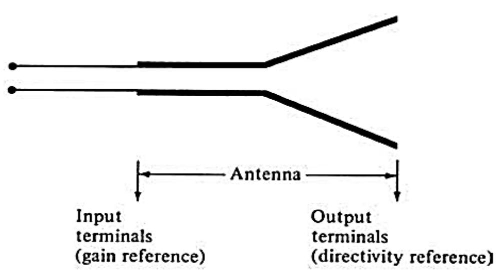
$$\eta_e = \frac{P_{radiated}}{P_{input}} \tag{3.06}$$

3.11 Antenna Efficiency

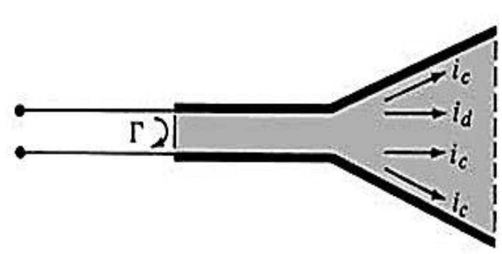
To measure the total efficiency of an antenna we need to take into account losses at the input terminals which is caused by impedance mismatch, conductive and dielectric materials.

$$e_o = e_r e_c e_d \tag{3.07}$$

Where $\boldsymbol{e_o}$= total efficiency, $\boldsymbol{e_r}$ = reflection mismatch efficiency, $\boldsymbol{e_c}$= conduction efficiency, $\boldsymbol{e_d}$ = dielectric efficiency. [3]



(a) Antenna reference terminals



(b) Reflection, conduction and dielectric losses

Figure 3.11: Reference terminals and losses of an antenna [3].

3.12 Beam Efficiency

The bar productivity can be characterized as the proportion of the bar range of the most bar to the full pillar range transmitted. It is another parameter that's habitually utilized to judge the quality of transmitting and getting antenna. The vitality when transmitted from an antenna, is anticipated agreeing to the antenna's directivity. The course in which a radio wire transmits more control has greatest proficiency, whereas a few of the vitality is misplaced in side flaps. The greatest vitality emanated by the pillar, with least misfortunes can be named as bar proficiency [4]. Mathematically it can be expressed as,

$$\eta_B = \frac{\Omega_{MA}}{\Omega_A} \tag{3.08}$$

Where, Ω_{MA} is beam area of the main beam and Ω_A is total solid beam angle (beam area).

3.13 Length Extension (ΔL)

The calculation of the extension of the length is given by the equation:

$$\Delta L = 0.412h \frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{3.09}$$

h = Thickness of the substrate

w = width of the patch

ϵ_{eff} = Effective dielectric constant

3.14 Voltage Standing Wave Ratio (VSWR)

This is the ratio of maximum value of standing wave voltage to its minimum value. The minimum VSWR for an antenna would be 1. The antenna with less VSWR has the better return loss compared to the other antenna. The impedance of the radio and transmission line must be matched to the antenna's impedance. The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.10}$$

Γ = voltage reflection coefficient at the input terminals of the antenna.

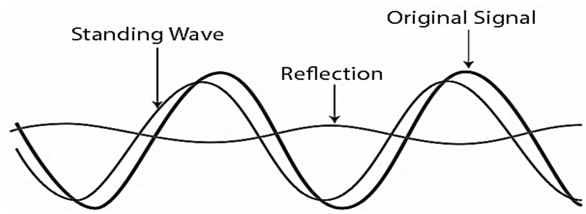


Figure 3.12: Representation of original, reflected and standing wave.

3.15 Return Loss (RL)

Return loss is the measure of reflected energy caused by the dissimilarity between impedances in metallic transmission lines and loads. It also can be regarded as the ratio, at the junction of a transmission line and a terminating impedance or other discontinuity, of the amplitude of reflected wave to the amplitude of the incident wave. Possible cause of excessive return loss include fluctuation in characteristic impedance, cable kinks, excessive bends, heating issue, cable jacket etc. [7].

Return loss is defined as the ratio of the reflected power to incident power. Mathematical expression of return loss is given below,

$$RL = 10log_{10}\left(\frac{P^+}{P^-}\right) = -20log_{10}(|\Gamma|)\ dB \tag{3.11}$$

Chapter 4 : Microstrip Patch Antenna

4.1 Introduction

Microstrip patch antenna is a metallic patch attached on a dielectric sheet (substrate) over a ground plane. In telecommunication, it means an antenna fabricated using microstrip techniques on a printed circuit board. Microtrip patch antenna is one kind of internal antenna. At microwave frequencies it is mostly used.

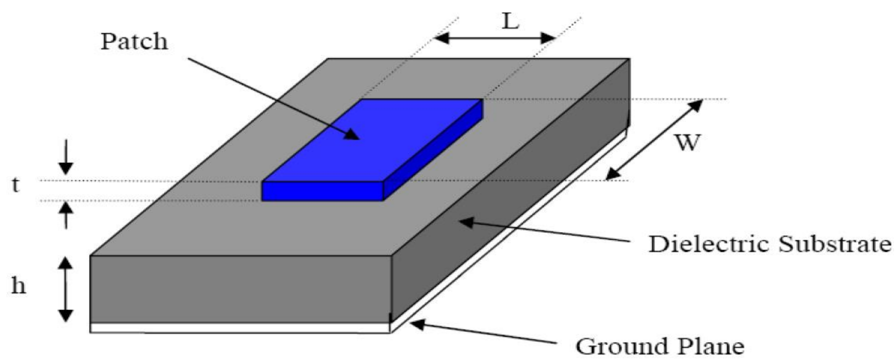


Figure 4.1: Structural design of microstrip patch antenna [3].

The microstrip patch is planned so its design greatest is ordinary to the patch. Conclusion fire radiation can moreover be fulfilled by reasonable mode choice. For a rectangular patch, the length L of the component is as a rule $\lambda 0/3 < L < \lambda 0/2$.The strip (patch) and the ground plane are isolated by a dielectric sheet (alluded to as the substrate), as appearing Figure 4.1. Dielectric constants are as a run the show inside the expand of $2.2 \leq \varepsilon r \leq 12$.The ones that are most alluring for great antenna execution are thick substrates whose dielectric consistent is within the lower conclusion of the extend since they give way better productivity, bigger bandwidth, freely bound areas for radiation into space, but at the cost of bigger component estimate. Lean substrates with higher dielectric constants are alluring for microwave circuitry since they require tightly bound areas to play down undesired radiation and coupling, and lead to littler component sizes; in any case, since of their more prominent misfortunes, they are less productive and have generally littler transmission capacities.

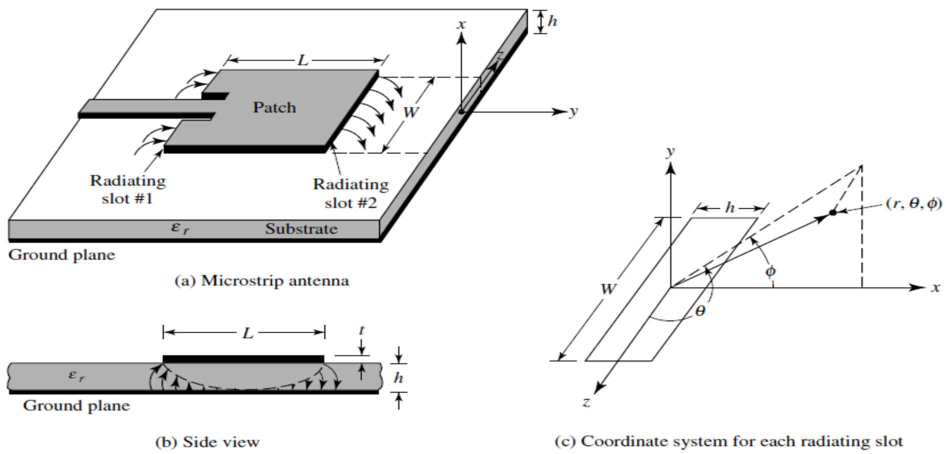


Figure 4.2: Microstrip antenna and coordinate system [3].

Microstrip antennas are said to as patch antennas. The transmitting components and the bolster lines are as a rule photo etched on the dielectric substrate. The emanating fix may be square, rectangular, lean strip (dipole), circular, circular, triangular, or any other arrangement. Figure 4.3.Square, rectangular, dipole (strip), and circular are the foremost common since of ease of investigation and manufacture, and their alluring radiation characteristics, particularly moo cross-polarization radiation [3].

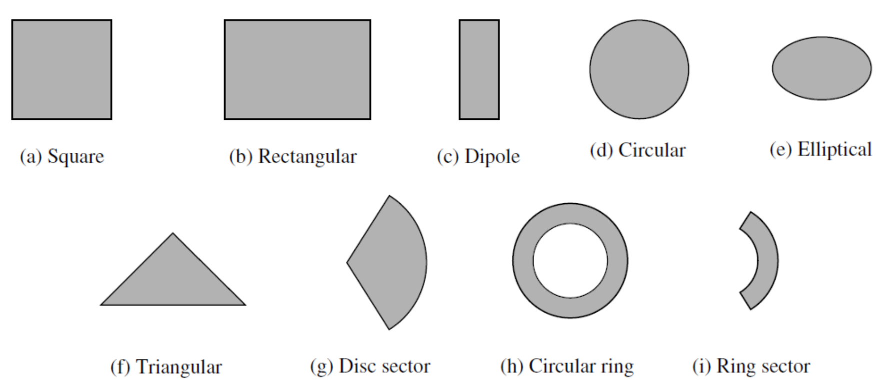


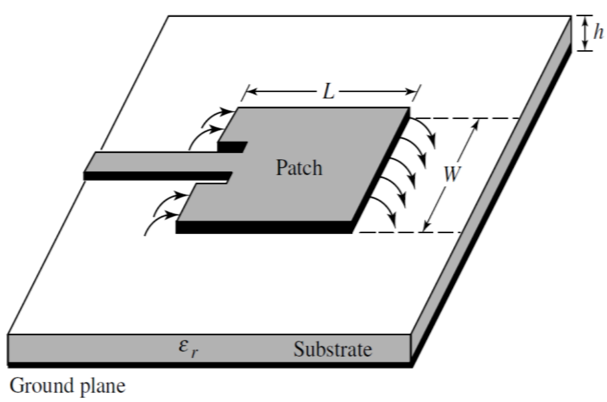
Figure 4.3: Representative shapes of microstrip patch elements [3].

4.2 Feeding Methods

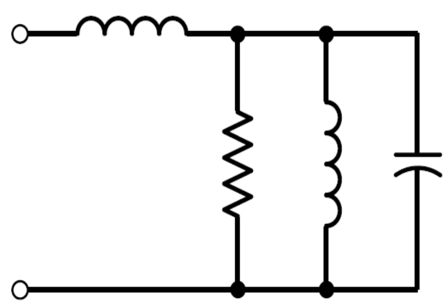
There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling.

4.2.1 Microstrip Line Feed

The microstrip nourish line is additionally a conducting strip, ordinarily of much littler width compared to the fix. The microstrip-line feed is simple to manufacture and or maybe basic to show. Microstrip substrate thickness increments, surface waves and spurious nourish radiation increment, which for commonsense plans constrain the transmission capacity (regularly 2–5%) [3].



(a) Microstrip line feed



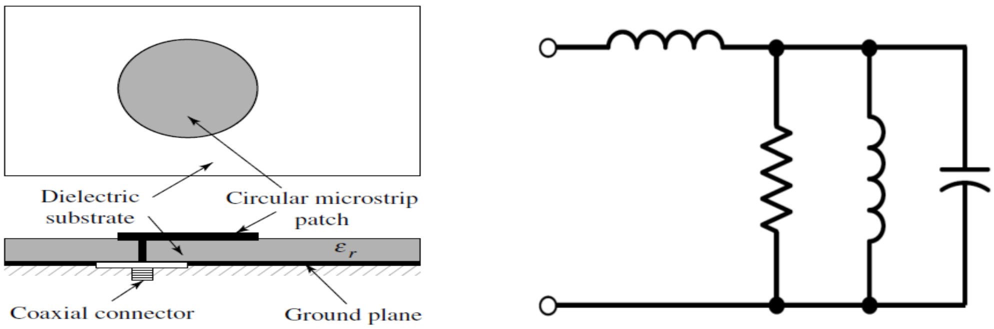
(b) Microstrip line circuit diagram

Figure 4.4: Microstrip line feed diagram and its circuit diagram [3].

4.2.2 Coaxial Feed

Test Feed-The coaxial nourish or test nourish may be an exceptionally common reaching plot of bolstering patch antennas. The inward conductor of the coaxial connector amplifies through the dielectric and is fastened to the emanating fix, whereas the external conductor is associated to the ground plane.

Coaxial-line nourishes, where the inward conductor of the coax is joined to the radiation patch whereas the external conductor is associated to the ground plane. The coaxial test nourish is additionally simple to manufacture. It too has limit transfer speed and it is more troublesome to demonstrate, particularly for thick substrates (h > 0.02λ0) [3].

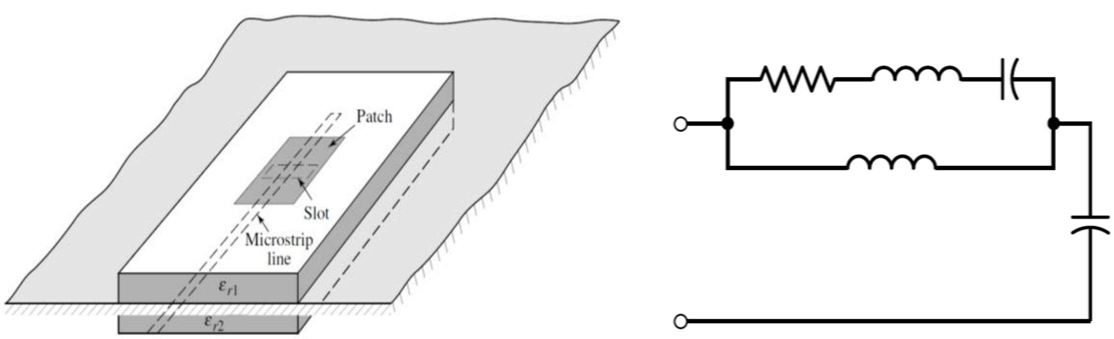


(a) Coaxial feed (b) Coaxial feed circuit diagram

Figure 4.5: The coaxial feed diagram and its circuit diagram [3].

4.2.3 Aperture Coupling

The opening coupling of is the foremost difficult of all four to manufacture and it too has limit transfer speed. Be that as it may, it is to some degree less demanding to show and has direct spurious radiation. The gap coupling comprises of two substrates isolated by a ground plane. On the foot side of the lower substrate there's a microstrip nourish line whose vitality is coupled to the fix through a space on the ground plane separating the two substrates [3].

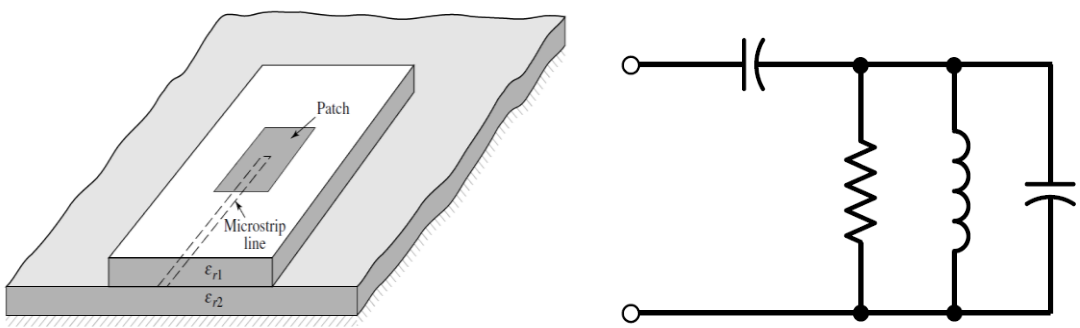


(a) Aperture coupling feed (b) Aperture coupling feed circuit diagram

Figure 4.6: Aperture coupling feed diagram and its circuit diagram.

4.2.4 Proximity-Coupled Feed

Vicinity Coupled Nourish This sort of nourish method is additionally called as the electromagnetic coupling conspire. As appeared in Figure 4.7, two dielectric substrates are utilized such that the bolster line is between the two substrates and the emanating fix is on beat of the upper substrate. The most advantage of this bolster method is that it kills spurious nourish radiation and gives exceptionally tall transmission capacity (as high as 13%) [6], due to by and large increment within the thickness of the microstrip patch antenna. This conspire too gives choices between two distinctive dielectric media, one for the patch and one for the nourish line to optimize the person exhibitions. The major drawback of this bolster conspire is that it is troublesome to manufacture because of the two dielectric layers which require legitimate arrangement. Too, there's an increment within the generally thickness of the antenna [3].



(a) Proximity-coupled feed (b) Proximity-coupled feed circuit diagram

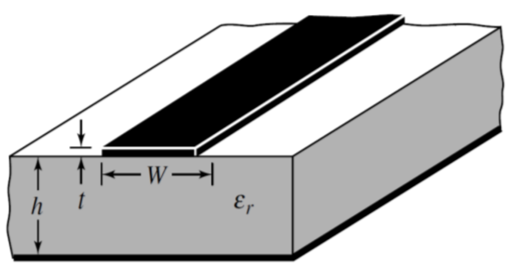
Figure 4.7: Proximity-coupled feed diagram and its circuit diagram [3].

4.3 Transmission-Line Model:

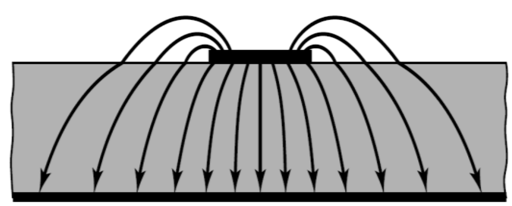
It was demonstrated prior that the transmission-line show is the most straightforward of all but it yields the slightest precise comes about and it needs the flexibility. A rectangular microstrip antenna can be spoken to as a cluster of two transmitting limit gaps (openings), each of width ‘W’ and thickness ‘h’, isolated by a remove ‘L’. Essentially the transmission-line show speaks to the microstrip antenna by two spaces, isolated by a low-impedance ‘Zc’ transmission line of length ‘L’ [3].

4.3.1 Fringing Effects

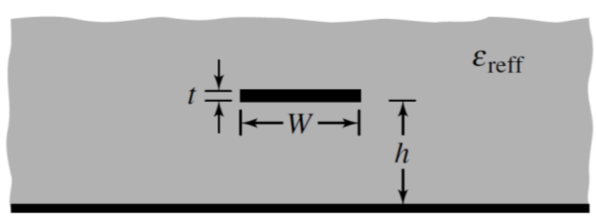
The measurements of the patch are limited along the length and width, the areas at the edges of the fix experience bordering. The sum of bordering may be a work of the measurements of the patch and the tallness of the substrate. For the foremost E-plane (xy-plane) bordering may be a work of the proportion of the length of the patch L to the stature h of the substrate (L/h) and the dielectric consistent 'ε_r' of the substrate. Since for microstrip radio wires L/h >> 1, bordering is decreased. For a microstrip line appeared in Figure 4.8(a), ordinary electric field lines are appeared in Figure 4.8(b). Usually a nonhomogeneous line of two dielectrics; regularly the substrate and discuss. As can be seen, most of the electric field lines reside within the substrate and parts of a few lines exist in discuss. As W/h >> 1 and ε_r >> 1, the electric field lines concentrate generally within the substrate. Bordering in this case makes the microstrip line look more extensive electrically compared to its physical measurements. Since a few of the waves travel within the substrate and some in discuss, a successful dielectric consistent ε_r is presented to account for bordering and the wave proliferation within the line [3].



(a) Microstrip line



(b) Electric field lines



(c) Effective dielectric constant

Figure 4.8: Microstrip line and its electric field lines, and effective dielectric constant geometry [3].

For a line with discuss over the substrate, the compelling dielectric consistent has values within the run of 1 < ε_{eff}< ε_r. For most applications where the dielectric steady of the substrate is much more noteworthy than solidarity (ε_r>> 1), the esteem of Ɛreff will be closer to the esteem of the real dielectric consistent ε_r of the substrate. The effective dielectric steady is additionally a work of recurrence [3].

The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they are given by

$$\epsilon_{eff} = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}[1 + 12\frac{h}{W}]^{-1/2} \tag{4.01}$$

4.3.2 Effective Length, Resonant Frequency, and Effective Width:

Since of the bordering impacts, electrically the fix of the microstrip antenna looks more noteworthy than its physical measurements. For the principal E-plane (xy-plane), this is demonstrated in Figure 4.9 where the dimensions of the patch along its length have been extended on each end by a distance 3L, which is a function of the effective dielectric constant ϵ_{eff} and the width-to-height ratio (W/h) [3].

A very popular and practical approximate relation for the normalized extension of the length is

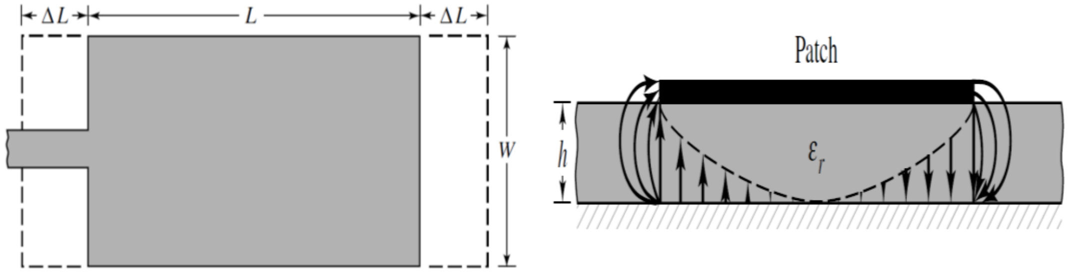
$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8)\right)} \tag{4.02}$$

Here 'W' is the width of patch and $W = \frac{c}{2f_o\sqrt{\frac{(\mathcal{E}_r+1)}{2}}}$ (4.03)

Since the length of the patch has been extended by 3L on each side, the effective length of the patch is now (L = λ/2)

$$L_{eff} = \boldsymbol{L + 2\Delta L} \tag{4.04}$$

Or, $L_{eff} = \frac{c}{2f_o\sqrt{\epsilon_{eff}}}$ (4.05)



(a) Top view (b) Side view

Figure 4.9: Physical and effective lengths of rectangular microstrip patch [3].

4.4 Microstrip Slot Antenna:

Microstrip slot antenna consists of a slot in the ground plane fed by a microstrip feed line. . They have the points of interest of being able to deliver bi-directional and unidirectional radiation designs. Fix and space combinations offer an extra degree of flexibility within the plan of microstrip antennas. This plan measure encourages the plan of radio wires with wanted polarization and they are less delicate to fabricating resiliences than are microstrip patch antennas. The slot can have the shape of a rectangle (narrow or wide), a circle or a ring slot as shown in Fig 4.10 [6].

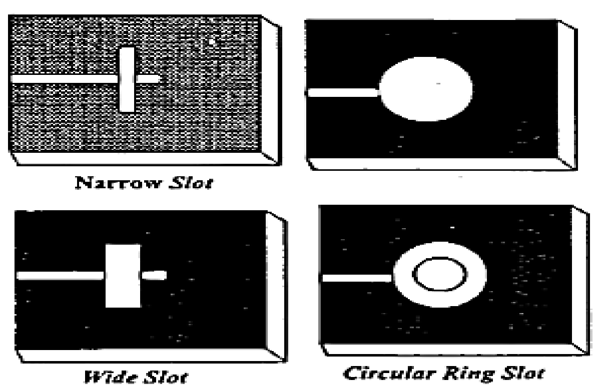


Figure 4.10: Microstrip Slot Antennas [6].

Table 1: Comparison of microstrip patch and microstrip slot antenna [6],[8]

Characteristics	Microstrip Patch Antenna	Microstrip Slotted Patch Antenna
Analysis and design	Easy	Easy
Fabrication	Very easy	Very easy
Tolerance in fabrication	Critical	Not very critical
Profile	Thin	Thin
Shape Flexibility	Any shape	Limited
Radiation fields	Unidirectional	Unidirectional and bidirectional
Polarization	Both Linear and circular	Both Linear and circular
Bandwidth	Narrow	Wide
Dual frequency operation	Possible	Possible
Spurious Radiation	Exists	Exists
Isolation between radiating elements	Fair	Good
Frequency scanning	Easily possible	Possible
Cross-polarization level	low	Very low
End-fire antenna	Not possible	Possible

4.5 Advantages and Limitations of Microstrip Patch Antennas

4.5.1 The advantages of microstrip patch antenna are:

Microstrip patch antennas and arrays are of huge commercial intrigued since of their various advantages.

- ❖ They operate at microwave frequencies.
- ❖ The microstrip patches of various shapes e.g. rectangular, square, triangular etc. are easily etched.

- They have lower fabrication cost.
- They support dual polarization types viz. linear and circular both.
- They are light in weight.
- Dual-frequency and dual-polarization designs possible.
- Compatible with integrated circuits.

These advantages that make microstrip patch antennas highly suitable for commercial mobile commercial, high-speed communication applications to make them perfect for the aperstructure and deft cluster concepts.

4.5.2 The limitations of microstrip antennas and arrays, as compared with conventional antennas are:

- It offers low efficiency due to dielectric losses and conductor losses.
- Narrow bandwidth and associated tolerance problems.
- It offers lower gain.
- Polarization purity hard to achieve.
- The microstrip antennas structure emanates from nourishes and other intersection focuses.
- Lower power handling capability (approximately 100 W).

In any case, a few of these impediments can be overcome through specialized methods. This proposition, for illustration, examines consolidating a U-slot into the plan to realize broad-band characteristics as well as using a cluster setup to attain craved pick up levels.

4.6 Applications:

Communication-based applications. Microstrip patch antenna finds several applications in wireless communication. the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the Microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication.

1. **Mobile and satellite communication application:**

Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems. There are different kinds of antennae like planar inverted-F antenna, folded inverted conformal antenna and mono pole. Also retractable whip antenna is commonly used in handsets. There are different kinds of antennae like planar inverted-F antenna, folded inverted conformal antenna and mono pole. Also retractable whip antenna is commonly used in handsets.

2. **Medical applications:**

Within the treatment of harmful tumors, microwave vitality is said to be the foremost successful way of actuating hyperthermia. The radiator to be utilized for this reason ought to be light-weight, simple to handle and rough. Only a patch radiator fulfils these requirements.

The initial designs of microstrip radiators for inducing hyperthermia were based on printed dipoles and annular rings that were designed on S-band (2-4 GHz). Later on the design was based on a circular microstrip disk at L-band (1-2 GHz). Two coupled microstrip lines with a flexible separation are used to measure temperature inside the human body. Fig. 5 shows a flexible patch applicator that operates at 430 MHz [8].

3. **Radio Frequency Identification (RFID):**

RFID employments in numerous ranges like portable communication, coordination's, fabricating, transportation and wellbeing care. RFID framework for the most part employments frequencies between 30 Hz and 5.8 GHz depending on its applications. Fundamentally, RFID framework could be a tag or transponder and a handset or peruses.

4. **Worldwide Interoperability for Microwave Access (WiMAX):**

The IEEE 802.16 standard is known as WiMAX. It can reach up to 30-mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMAX compliant communication equipment.

5. **Textile antennae: recent research:**

There are some applications at present where antennae are used to continuously monitor biometric data of the human body. In order to do this, they need to be so close to the human body all the time that they can continuously monitor the biometric data and send the information to the outside world. If the antenna is hard, it cannot be kept always attached with the human body. An antenna made of textile material will not harm the human body and can be worn for extended periods. Wearable antennae will find use in healthcare, recreation, fire-fighting, etc. [8].

Chapter 5 : Antenna Design with CST Microwave Studio

5.1 Introduction to CST Microwave Studio:

CST MICROWAVE STUDIO® is a completely highlighted software bundle for electromagnetic analysis and design in the high recurrence range. It improves the way toward contributing the structure by giving a powerful solid modeling front end which depends on the ACIS demonstrating portion. Solid realistic input improves the meaning of your gadget considerably further. After the segment has been demonstrated, a completely programmed cross section method is connected before a reenactment motor is turned over. A key element of CST MICROWAVE STUDIO® is the Method on Demand™ approach which permits utilizing the test system or work type that is most appropriate to a specific issue.

Since no one method works similarly well for all applications, the software contains several different simulation techniques for example, transient solver, recurrence area solver, vital condition solver, multilayer solver, asymptotic solver, and eigenmode solver to best suit different applications. The recurrence area solver additionally contains specific strategies for examining highly resonant structures such as filters. CST STUDIO SUITE® is a product bundle for structuring, reproducing and streamlining electromagnetic frameworks. It is utilized in driving innovation and building organizations around the world. The three pillars of CST® products are accuracy, speed and usability.

Each solver's simulation results can be visualized with a variety of different options. Again, a strongly interactive interface will help you achieve the desired insight into your device quickly [9],[10].

5.2 Some Key Features of CST MWS:

5.2.1 General Features

- ❖ Native graphical user interface based on Windows XP, Windows Vista, Windows 7, Window 8 and Window 10.
- ❖ Fast and memory efficient Finite Integration Technique.
- ❖ Extremely good performance due to Perfect Boundary Approximation (PBA) feature for solvers using a hexahedral grid. The transient and Eigen mode solvers also support the Thin Sheet Technique (TST).
- ❖ The structure can be viewed either as a 3D model or as a schematic. The latter allows for easy coupling of EM simulation with circuit simulation.

5.2.2 Structure Modeling

- ❖ Advanced ACIS1-based, parametric solid modeling front end with excellent structure visualization.
- ❖ Feature-based hybrid modeler allows quick structural changes.
- ❖ Import of 3D CAD data by SAT, Autodesk Inventor, IGES, VDA-FS, STEP, ProE, CATIA 4, CATIA 5, CoventorWare, Mecadtron, Nastran, STL or OBJ files.
- ❖ Import of 2D CAD data by DXF, GDSII and Gerber RS274X, RS274D files.
- ❖ Import of EDA data from design flows including Cadence Allegro / APD / SiP, Mentor Graphics Expedition®, Mentor Graphics PADS® and ODB++.
- ❖ Import of PCB designs originating from Simlab PCBMod / CST PCBStudio.
- ❖ Import of 2D and 3D sub models.
- ❖ Import of Agilent ADS® layouts.
- ❖ Import of Sonnet® EM models (8.5x).
- ❖ Import of a visible human model dataset or other voxel datasets.
- ❖ Export of CAD data by SAT, IGES, STEP, NASTRAN, STL, DXF, Gerber, DRC or POV files.
- ❖ Parameterization for imported CAD files.
- ❖ Material database.
- ❖ Structure templates for simplified problem description.

5.2.3Transient Simulator

- ❖ Efficient calculation for loss-free and lossy structures.
- ❖ Broadband calculation of S-parameters from one single calculation run by applying DFTs to time signals.
- ❖ Calculation of field distributions as a function of time or at multiple selected frequencies from one simulation run.
- ❖ Adaptive mesh refinement in 3D.
- ❖ Parallelization of the transient solver run.
- ❖ Isotropic and anisotropic material properties.
- ❖ Frequency dependent material properties.
- ❖ Surface impedance model for good conductors.
- ❖ Port mode calculation by a 2D eigenmode solver in the frequency domain
- ❖ S-parameter symmetry option to decrease solve time for many structures Calculation of various electromagnetic quantities such as electric fields, magnetic fields, surface currents, power flows, current densities, power loss densities, electric energy densities, magnetic energy densities, voltages in time and frequency domain.
- ❖ Antenna farfield calculation (including gain, beam direction, side lobe suppression, etc.) with and without farfield approximation at multiple selected frequencies.
- ❖ Broadband farfield monitors and farfield probes to determine broadband farfield information over a wide angular range or at certain angles respectively.
- ❖ Antenna array farfield calculation and etc.

5.2.4 Frequency Domain Simulator

- ❖ Efficient calculation for loss-free and lossy structures including lossy waveguide ports.
- ❖ General purpose solver supports both hexahedral and tetrahedral meshes
- ❖ Isotropic and anisotropic material properties.
- ❖ Arbitrary frequency dependent material properties.

- Surface impedance model for good conductors, Ohmic sheets and corrugated walls (tetrahedral mesh only).
- Inhomogeneously biased Ferrites with a static biasing field (tetrahedral mesh only).
- Automatic fast broadband adaptive frequency sweep.
- User defined frequency sweeps.
- Continuation of the solver run with additional.
- Phase de-embedding of S-parameters.
- Calculation of various electromagnetic quantities such as electric fields, magnetic fields, surface currents, power flows, current densities, power loss densities, electric energy densities, magnetic energy densities and etc.

5.2.5 Integral Equation Simulator

- Efficient calculation for loss-free and lossy structures including lossy waveguide ports.
- Surface mesh discretization.
- Isotropic and anisotropic material properties.
- Arbitrary frequency dependent material properties.
- Automatic fast broadband adaptive frequency sweep.
- User defined frequency sweeps.
- Direct and iterative matrix solvers with convergence acceleration techniques.
- Higher order representation of the fields including mixed order.
- Single and double precision floating-point representation.
- Discrete face port excitation.
- Waveguide port excitation.
- Plane wave excitation.
- Farfield excitation.

5.2.6 Eigenmode Simulator

- Calculation of modal field distributions in closed loss free or lossy structures.
- Isotropic and anisotropic materials.
- Parallelization.
- Adaptive mesh refinement in 3D.
- Automatic parameter studies using built-in parameter sweep tool.
- Automatic structure optimization for arbitrary goals using built-in optimizer and etc.

5.2.7 CST DESIGN STUDIO View

- Represents a schematic view that shows the circuit level description of the current CST MWS project.
- Allows additional wiring, including active and passive circuit elements as well as more complex circuit models coming from measured data such as Touchstone or IBIS files, analytical or semi analytical descriptions like microstrip or stripline models or from simulated results.
- Offers many different circuit simulation methods, including transient EM/circuit co- simulations.
- All schematic elements as well as all defined parameters of the connected CST MWS project can be parameterized and are ready for optimization runs.

5.2.8 Visualization and Secondary Result Calculation

- Multiple 1D result view support.
- Displays S-parameters in xy-plots (linear or logarithmic scale).
- Displays S-parameters in Smith charts and polar charts.
- Online visualization of intermediate results during simulation.
- Import and visualization of external xy-data.
- Copy / paste of xy-datasets.
- Fast access to parametric data via interactive tuning sliders.
- Displays port modes (with propagation constant, impedance, etc.).

- Various field visualization options in 2D and 3D for electric fields, magnetic fields, power flows, surface currents, etc.
- Animation of field distributions.
- Calculation and display of farfields (fields, gain, directivity, RCS) in xy-plots, polar plots, scattering maps and radiation plots (3D).
- Calculation of Specific Absorption Rate (SAR) including averaging over specified mass.
- Calculation of surface losses by perturbation method and Q factor.
- Display and integration of 2D and 3D fields along arbitrary curves.
- Integration of 3D fields across arbitrary faces.
- Automatic extraction of SPICE network models for arbitrary topologies ensuring the passivity of the extracted circuits.
- Combination of results from different port excitations.
- Hierarchical result templates for automated extraction and visualization of arbitrary results from various simulation runs. These data can also be used for the definition of optimization goals.

5.2.9 Result Export

- Export of S-parameter data as TOUCHSTONE files.
- Export of result data such as fields, curves, etc. as ASCII files.
- Export screen shots of result field plots.
- Export of farfield data as excitation for integral equation solver.
- Export of nearfield data from transient or frequency domain solver as excitation in transient solver [9],[10].

5.3 Solver technology [11]

A. High frequency:

- Transient solver – general purpose.
- Frequency domain solver – general purpose.
- Integral equation solver – electrically large structures, RCS.
- Asymptotic solver – installed performance, RCS.

- ❖ Eigen mode solver – resonant cavities.
- ❖ Multilayer solver – planar structures.
- ❖ Filter Designer 2D – RF filter analysis and synthesis.
- ❖ Filter Designer 3D – cross-coupled cavity filter synthesis.

B. Low Frequency:

- ❖ Electrostatic / Magneto static – fast static simulation.
- ❖ Stationary current solver – DC applications.
- ❖ Time domain solver – non-linear materials, transient effects.
- ❖ Frequency domain solver – eddy currents, displacement current.

C. EDA:

- ❖ PEEC solver – boards without reference planes.
- ❖ Transmission line solver – signal integrity.
- ❖ 3D FEFD solver – power integrity.
- ❖ Rule Check – EMC and SI on PCB.

D. Practical Dynamics:

- ❖ Particle tracking solver – low energy particles, electron guns.
- ❖ PIC solver – high energy particles, RF devices.
- ❖ Wake field solver – accelerator components.

E. Multiphysics:

- ❖ Thermal solvers – electromagnetic heating, bio heat.
- ❖ Structural mechanics solver – thermal expansion, deformation.

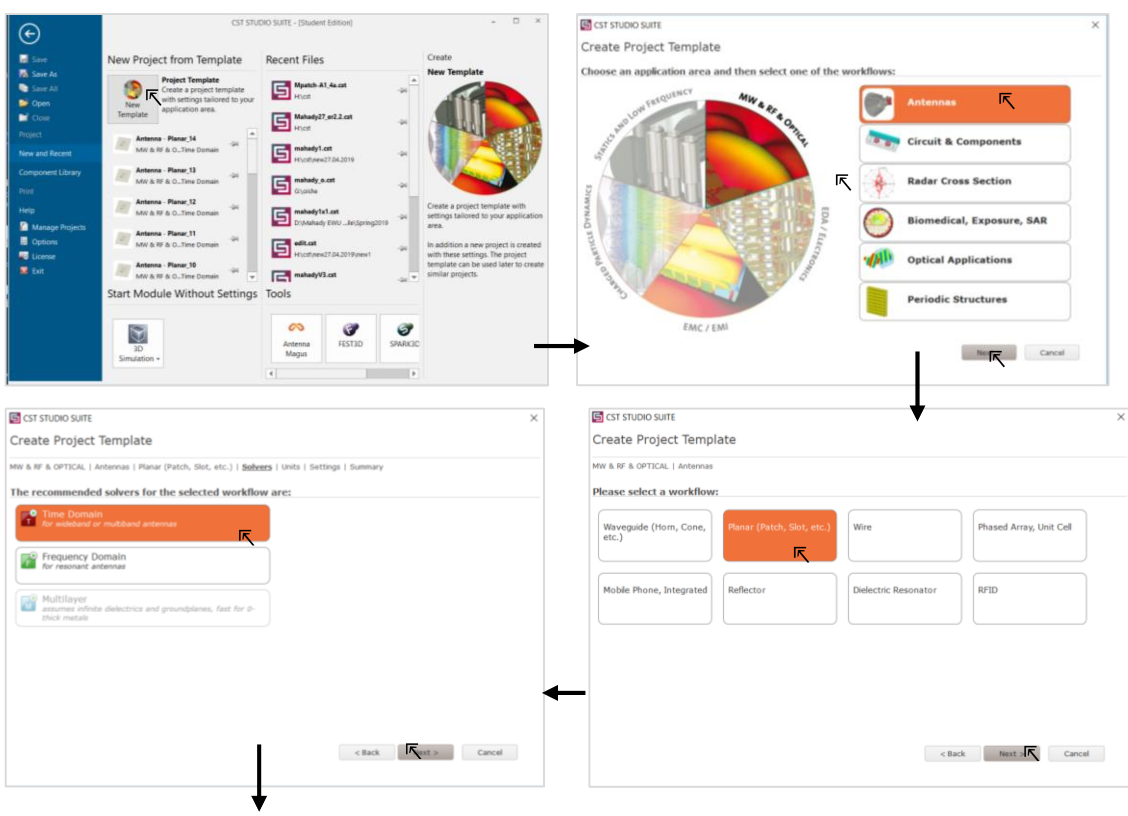
F. EMC:

- ❖ Transmission line matrix (TLM) solver – general purpose, EMC.
- ❖ Cable solver – cable harness simulation.
- ❖ Rule Check – EMC and SI on PCBs.

5.4 Antenna Designing and Performance Analysis:

5.4.1 Rectangular microstrip patch Antenna Design Procedure:

At first, from start menu select Programs > CST STUDIO SUITE 2018 and after that tap on the new project>MW, RF & Optics>Antenna. There will be different types of antenna, from choice we chose planer antenna. Next, we will choose the time domain solver for the workflow. Then click next a new window will come that shows the parameters with their units. Now we have to make sure that the frequency is in ‘GHz’, Lengths in ‘mm’ and others parameters will be cleared out unaltered. Presently it is time to set the frequency range and select what we need to monitor. Let the frequency range from 3.1 to 5.1 Ghz and define the operating frequency at 4.1 GHz. We’ll mainly monitor electric field, magnetic field and far-field for the defined frequency. Presently it’s time to donate a title to the venture and let it ‘Antenna_1.1’. After clicking okay a hexahedral lattice will show up on working plane.



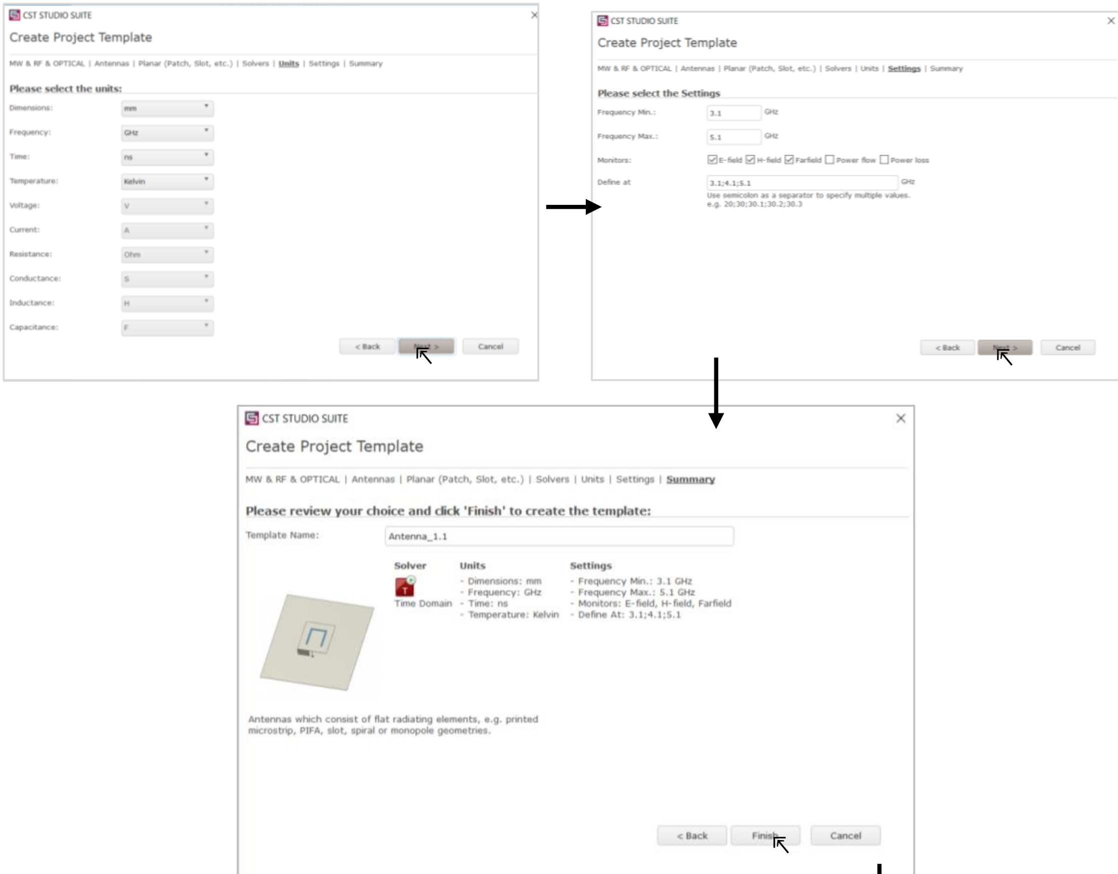


Figure 5.1: Steps to create project template.

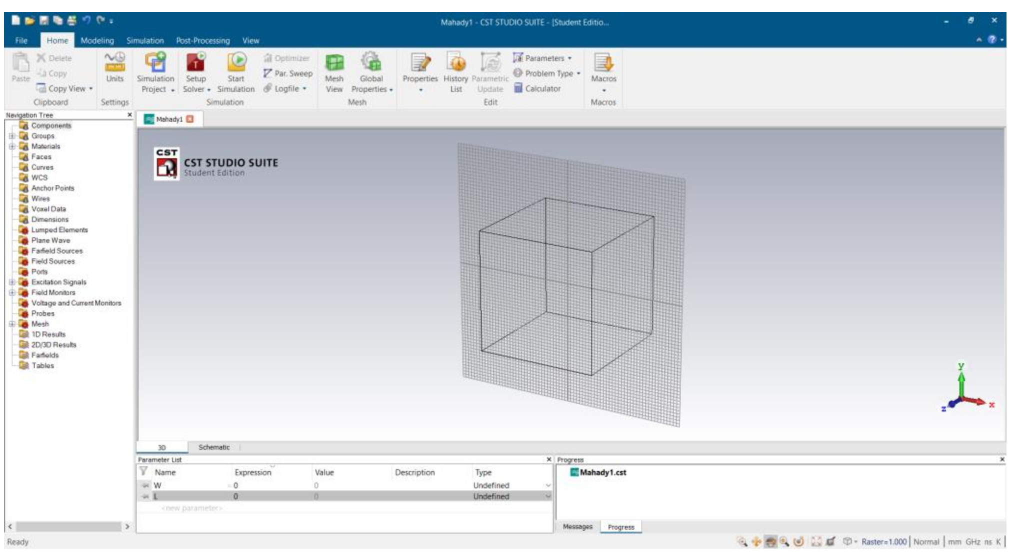


Figure 5.2: CST MWS's working plane.

Now it is time to design a rectangular patch antenna. When designing a microstrip patch antenna there are parameters that need to be calculated first like the length and the width of the patch. The parameters required for the antenna design can be calculated by manually or MATLAB code or Microstrip Patch Antenna Calculator. We also calculate the feedline width from CST for impedance matching, the step is shown below in Fig. 5.3.

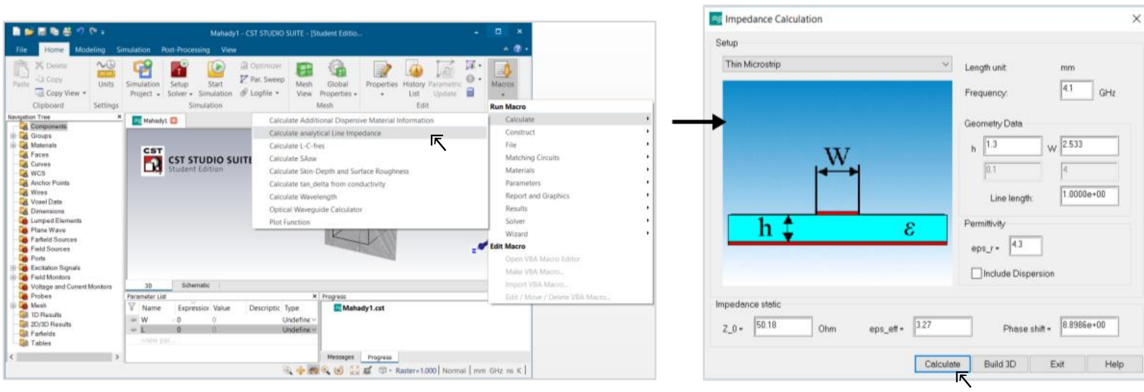


Figure 5.3: Step to calculate feedline width.

Now we will put the parameter values in the parameter list.

Table 2: Parameter list with values to design 'Antenna_1.1'

Parameter	Length (in mm)
Ground Length (Lg)	34.54
Ground Width (Wg)	44.92
Patch Length (L)	17.27
Patch Width (W)	22.46
Feed line Length (Fi)	3.9
Feed line Width (Wf)	2.53
Gap- Patch & Feed (Gpf)	0.3
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.3

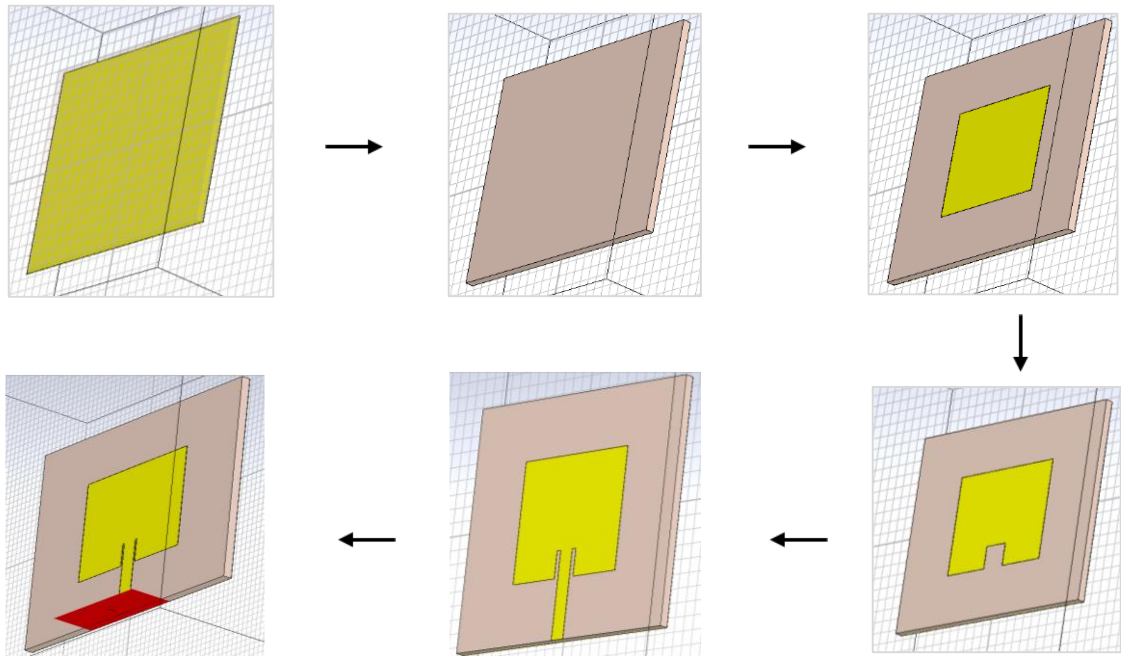


Figure 5.4: Basic design of patch antenna

Now we have to design a ground plane, steps are going to the modeling window> click on the brick>press Esc key on keyboard and give the specified values for ground plane also select Copper (annealed) as the material. Then we have to put a substrate on the ground and the dimension would be the same as ground plane and select the material FR-4(lossy). Then the block of radiating patch is then placed on top of the substrate and the radiating patch consist of height of 'ht' mm which is similar to that of the ground plane. The dimension value will be specific which we have calculated for patch and used Copper (annealed) as the material. Then create an empty space for feed line and the gap between the patch and the inset-fed (Gpf) where the material is nickel and cut the portion. Now the next step is to add the feed line which is also made of annealed copper and add it with the patch using the Boolean method. Now we have to create the waveguide port to zoom in the portion of feedline and double click on the phase of feedline, also make sure that the distance of reference plane is zero. Before starting our simulation we have to go field monitor and set the range of frequency and the resonant frequency. Then we have to select some particular field option which we have to see in our simulation. In our work, we select E-field, H-field and farfield; also set the label of operating frequency. Now we are done with the setting so have to start simulation. We have followed the same steps to design an antenna operating at 3.5GHz.

To add slots in an antenna go to modeling window> click on the brick>press Esc key on keyboard and give the specified values for where we want to slot also select vacuum as the material and cut the portion. This step is repeated depending on how many times we want to slot.

5.4.2 Design and Performance Analysis of Microstrip Patch Antennas with and without Slot for 4.1GHz:

5.4.2.1 Antenna_1.1 without slot:

The required parameters to design 'Antenna_1.1' is given in Table 2. The designed antenna is shown in Fig. 5.5.

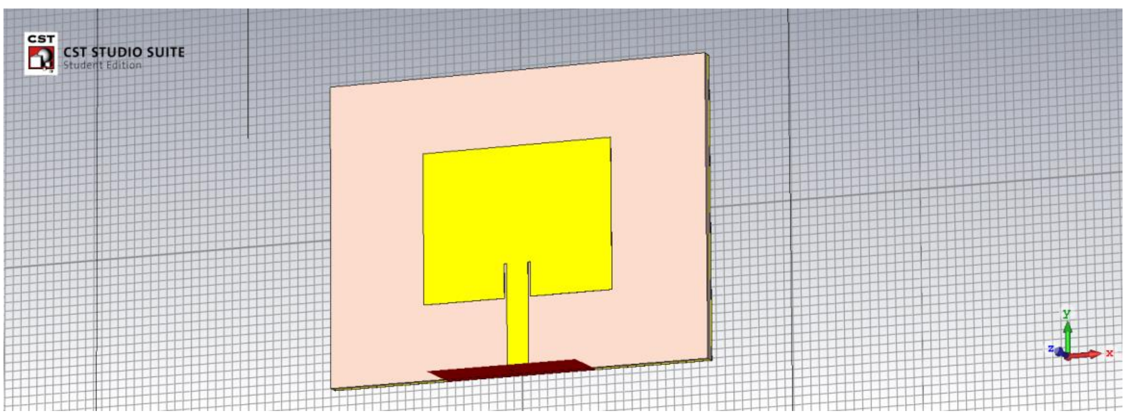


Figure 5.5: Antenna1.1

In this case the resonant frequency will be 4.1GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.3mm is chosen as the substrate material for the patch antenna.

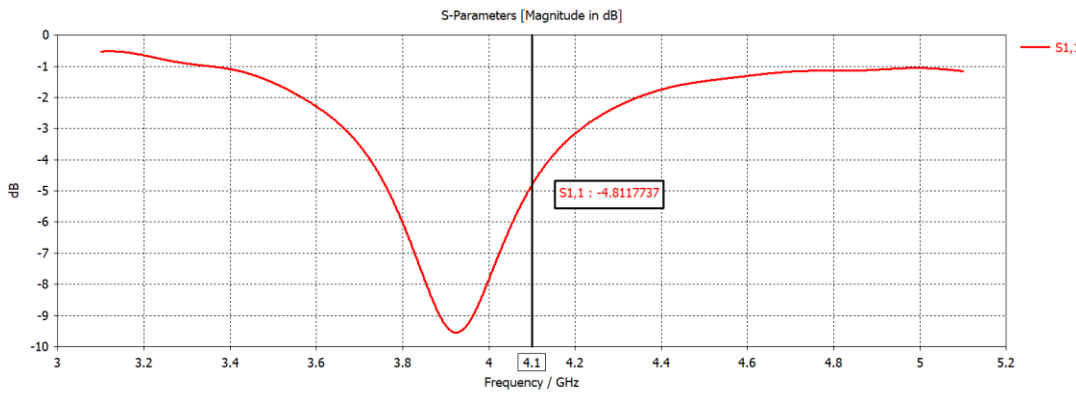


Figure 5.6: Return loss of 'Antenna_1.1'

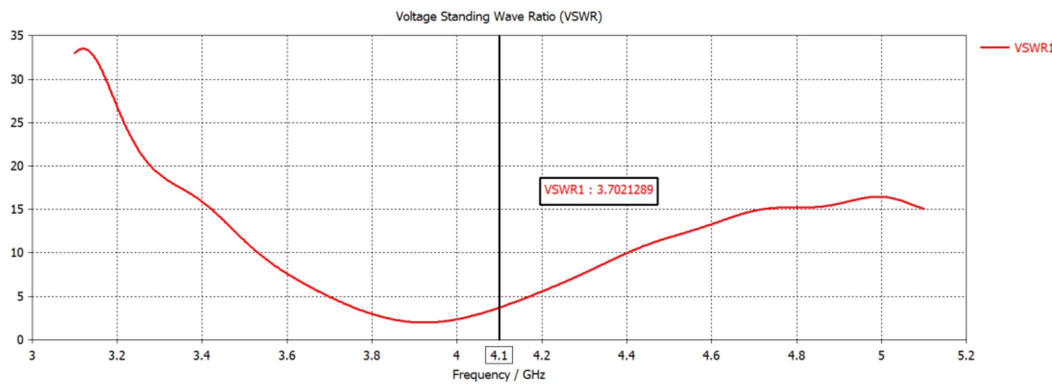


Figure 5.7: Standing wave ratio for 'Antenna_1.1'

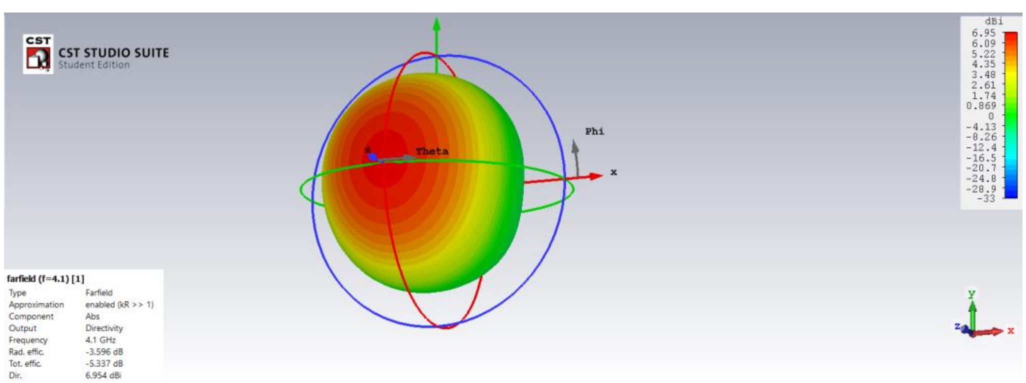


Figure 5.8: Far field radiation pattern (directivity) in 3D form for 'Antenna_1.1'

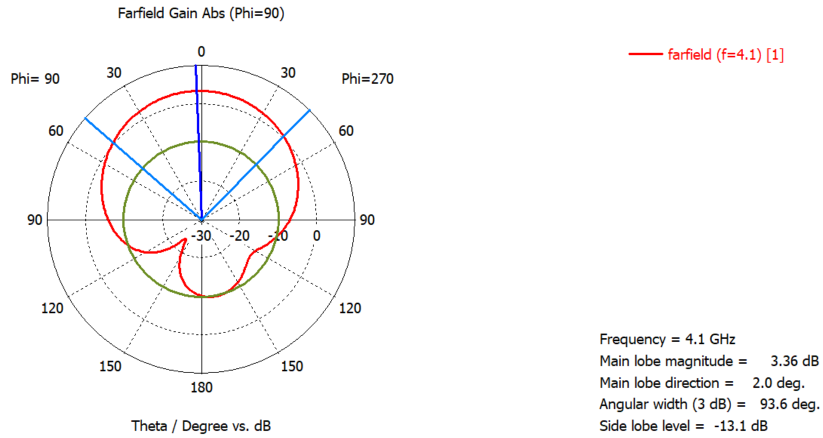


Figure 5.9: Far field radiation pattern (gain) in polar form for 'Antenna_1.1'

S11 represents how much power is reflected from the antenna, and that is known as the return loss. It is a parameter that is used to measure the power reflected by the antenna due to the mismatch of the antenna. If the return loss is 0dB then the radiation of an antenna is zero so all the power is reflected from the antenna. That means that the power input equal to the power reflected. If S11= -10dB then 90 percent power is delivered to the antenna. From the Fig. 5.6 of the return loss given above it shows very poor result which means that most of the power was reflected from the antenna because above -10dB return loss is bad which means less power is delivered to the antenna. Here the return loss of Antenna_1.1 at 4.1GHz is nearly -4.81dB so much less power delivered to the antenna. The antenna was designed to operate at 4.1 GHz, but it is resonant at approximately 3.94GHz. This shift is due to the fringing fields around the antenna. This is not our expected result. To achieve better result by shifting the resonant frequency at desired frequency, we will slot the antenna and also change some parameter value [12].

5.4.2.2 Antenna_1.2 with complex slot:

Table 3: Parameter list with values to design 'Antenna 1.2'.

Parameter	Length (in mm)
Ground Length (Lg)	34.54
Ground Width (Wg)	44.92
Patch Length (L)	17.27
Patch Width (W)	22.46
Feed line Length (Fi)	3.9
Feed line Width (Wf)	2.53
Gap- Patch & Feed (Gpf)	0.3
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.3

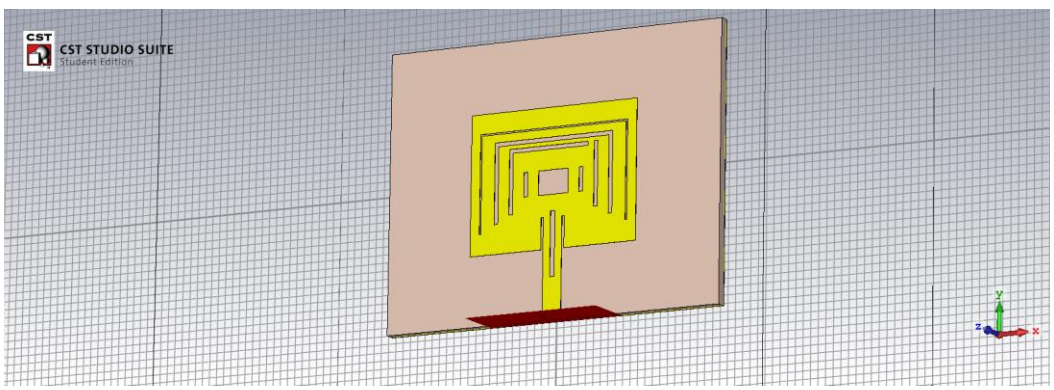


Figure 5.10: Antenna_1.2

In this case the resonant frequency will be 4.1GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.3mm is chosen as the substrate material for the patch antenna. The parameter value of 'Antenna_1.2' in Table:3 is same as 'Antenna_1.1' parameter which is given in Table:2 and here we are adding slots in the antenna.

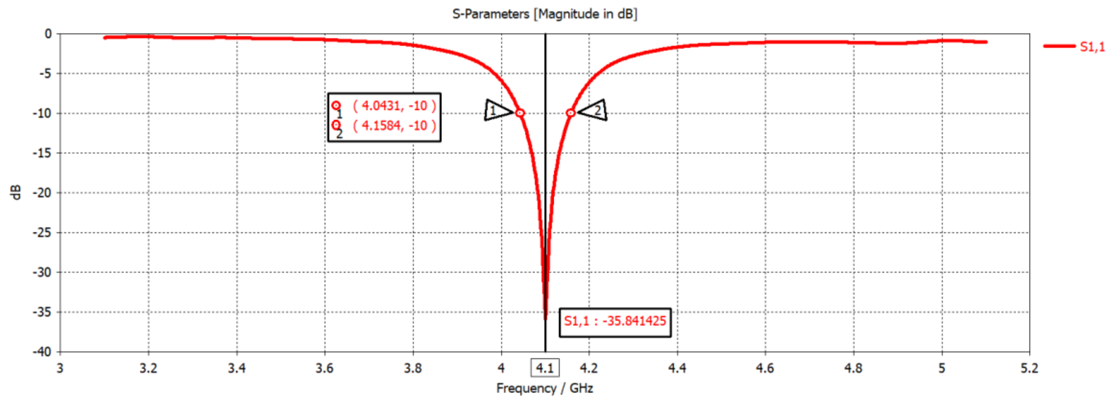


Figure 5.11: Return loss of 'Antenna_1.2'

The return loss vs frequency curve of 'Antenna1.2' given in Fig. 5.11 shows that the minimum return loss is -35.84dB which means almost all the power is delivered to the antenna. The designed antenna resonates at 4.1 GHz. The return loss at 4.1 GHz is -35.84dB, this value implies good matching below the -10dB region. The transmission capacity of the proposed patch antenna is 115.3MHz.

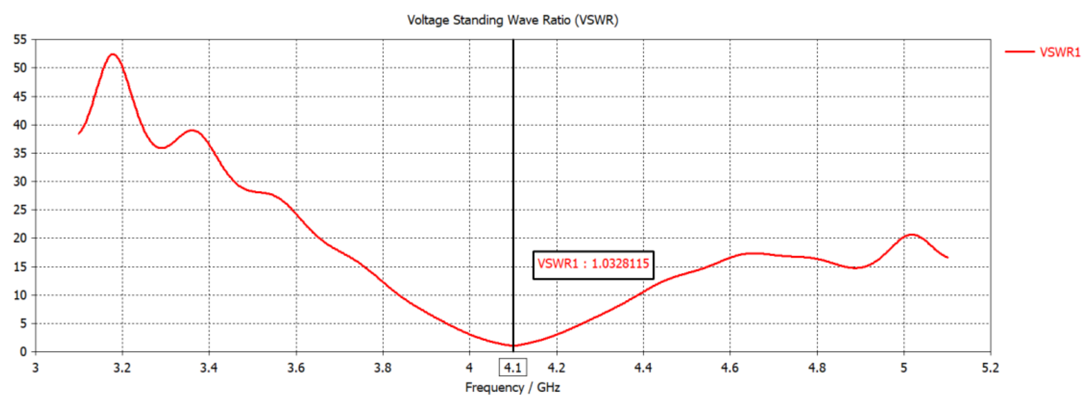


Figure 5.12: Standing wave ratio for 'Antenna_1.2'

VSWR is a function of the reflection coefficient and VSWR stands for Voltage Standing Wave Ratio, which describes the power reflected from the antenna or describes how well the antenna is impedance matched to the transmission line and power is transmitted. VSWR must lie in the range of 1 to less than 3. In general case VSWR must lie in the rage of 1-2 and the antenna match is considered to be very good. VSWR is always a real and positive number for antenna. The value of smaller VSWR indicate the better result, which means the antenna is matched to the transmission line perfectly and the more power is delivered to the antenna. The minimum VSWR is 1. For this situation, no power is reflected from the antenna, which is perfect. The VSWR of the microstrip patch antenna is shown in the Fig. 5.12. From the figure we see VSWR is 1.0328 for the frequency of 4.1GHz which is very close to 1. So that the antenna is performing very well according to theory and delivered almost maximum power [12],[13].

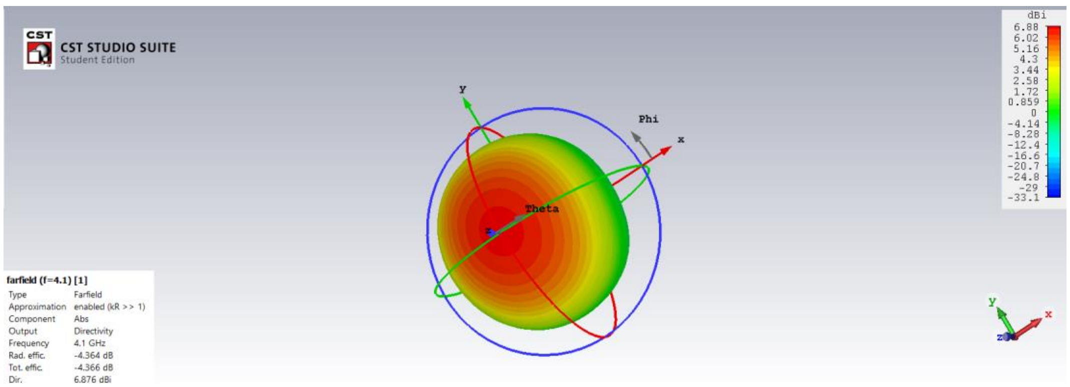


Figure 5.13: Far field radiation pattern (directivity) in 3D form for ‘Antenna_1.2’

The 3D radiation pattern for the antenna_1.2 at 4.1 GHz is shown in Fig. 5.13. The directivity of ‘Antenna_1.2’ is 6.876dBi. It is a measure of how 'directional' an antenna's radiation pattern is. So directivity can be understood as a direction of maximum radiation by an antenna. Our antenna radiation pattern is directional that means not equally radiated in all direction. The directivity of patch antennas is approximately 5-7dBi. Here we clearly see from the figure where there is red color means much more radiation in that direction. Hence the three dimensional diagram is self-explanatory [12].

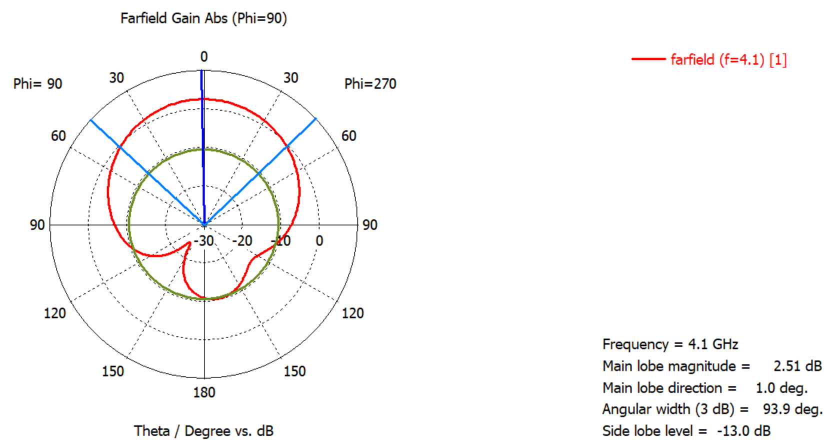


Figure 5.14: Far field radiation pattern (gain) in polar form for 'Antenna_1.2'

Far field radiation pattern (gain) in polar form for 'Antenna 1.2' is 2.51dB which is shown in Fig. 5.14. The beam main lobe direction for 'Antenna_1.2' is 1 degree with beam width 93.9 degree. Main lobe is the radiation lobe containing the direction of maximum radiation. Side lobes are generally the largest among the minor lobe, the minor lobes adjacent to the main lobe. Here the side lobe is -13dB. The beam width of the antenna is a very important figure-of-merit, and it often used as a tradeoff between it and the side lobe level. By controlling the width of the beam, the gain of antenna can be increased or decreased. By narrowing the beam width, the gain will increase. Antennas with wide beam widths typically have low gain and antennas with narrow beam widths avail to have higher gain [14],[15].

5.4.2.3 Antenna_1.3 with simple slot:

Table 4: Parameter list with values to design 'Antenna_1.3'

Parameter	Length (in mm)
Ground Length (Lg)	25.07
Ground Width (Wg)	30.26
Patch Length (L)	17.27
Patch Width (W)	22.46
Feed line Length (Fi)	3.9
Feed line Width (Wf)	2.53
Gap- Patch & Feed (Gpf)	1
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.3

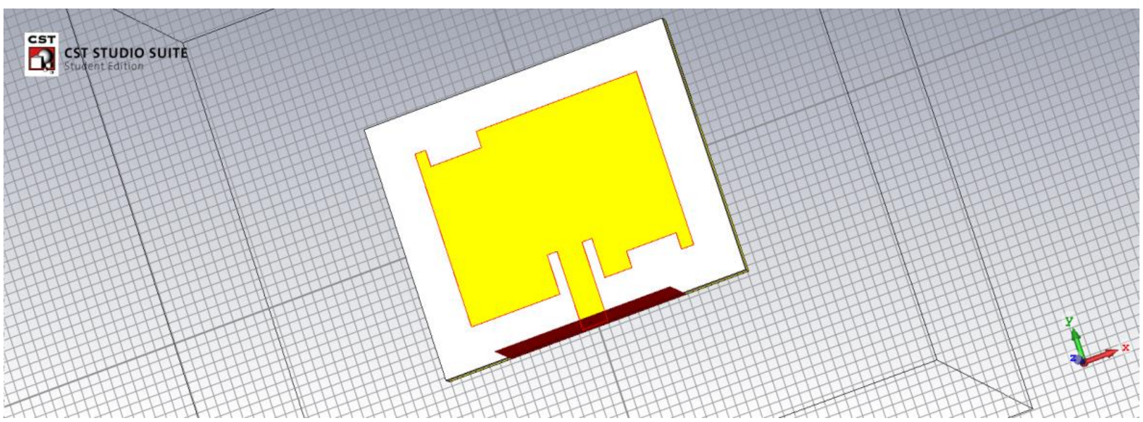


Figure 5.15: Antenna_1.3

In this case the resonant frequency will be 4.1GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.3mm is chosen as the substrate material for the patch antenna. Here for 'Antenna 1.3' the value of Wg, Lg and Gpf have been changed from previous antenna (Antenna_1.1 and Antenna_1.2) value and also slots have been inserted in the antenna. This antenna size is much smaller than other two antennas designed for 4.1GHz.

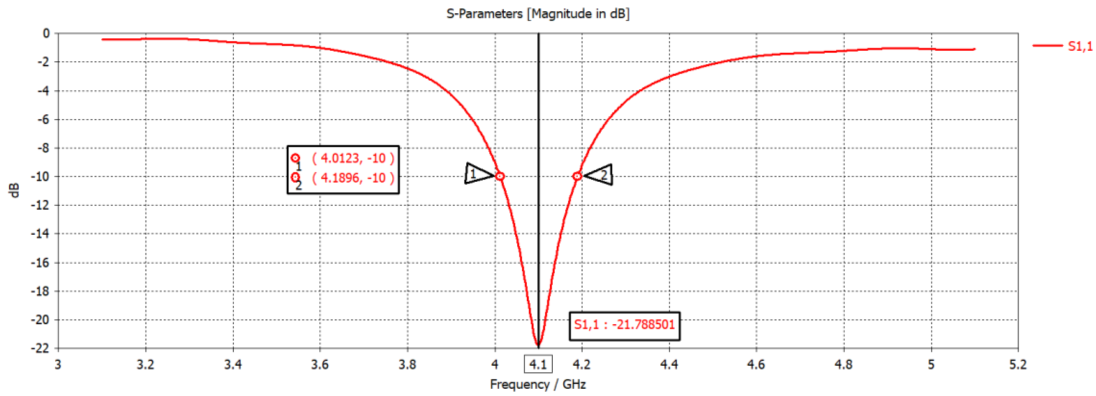


Figure 5.16: Return loss of 'Antenna_1.3'

The return loss vs frequency curve of 'Antenna_1.3' given in Fig.5.16, which shows that the return loss is much lower than the -10dB level which is -21.789dB. The result can be considered good as a return loss of -21.789dB means almost all the power was delivered to the antenna. The designed antenna resonates at 4.1 GHz. The return loss at 4.1 GHz is -21.789dB, so power is delivered to the antenna. The bandwidth of the proposed patch antenna is 177.3MHz. If we compare the return loss of 'Antenna_1.3' and 'Antenna_1.2' the bandwidth of 'Antenna_1.3' is increased and the return loss is decreased [12].

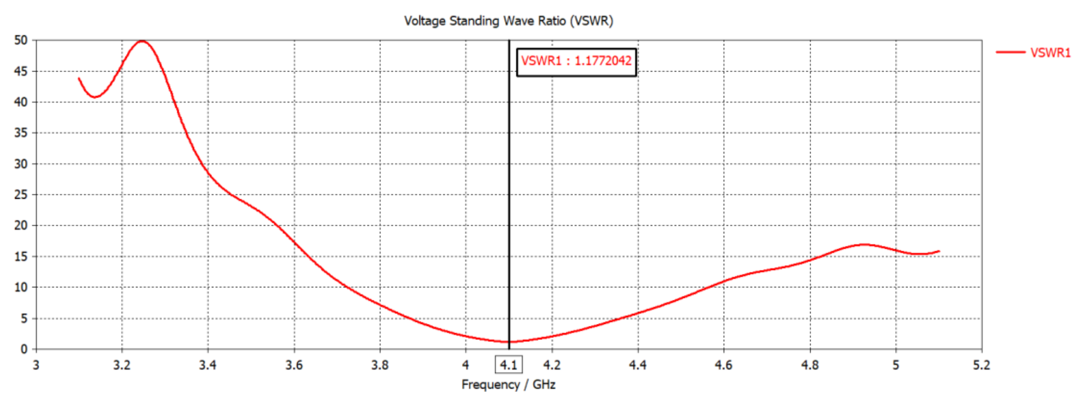


Figure 5.17: Standing wave ratio for 'Antenna_1.3'

We already said that "VSWR must lie in the range of 1 to less than 3. In general case VSWR must lie in the rage of 1-2 and the antenna match is considered very good". The value of smaller VSWR indicate the better result. Which is the antenna is matched to the transmission line perfectly and the more power is delivered to the antenna. The minimum

VSWR is 1. For this situation, no power is reflected from the antenna, which is perfect. The VSWR of the microstrip patch antenna is shown in the Fig.5.17. From the figure we see VSWR is 1.1772 at the frequency of 4.1GHz which is close to 1. So that the antenna is performing very well according to theory and delivered almost maximum power. If we compared to 'Antenna_1.2" and 'Antenna_1.3' we will see the big difference between them. The value of VSWR for 'Antenna_1.3' is higher than 'Antenna_1.2' because VSWR is directly related to return loss value. Here the return loss value for 'Antenna_1.3' is less than 'Antenna_1.2'. So, we can say if the 'Antenna_1.2' has 0.03% reflection and 99.97% power transmitted to the antenna than 'Antenna_1.3' has 0.66% reflection and 99.4% power transmitted to the antenna [12],[13],[16].

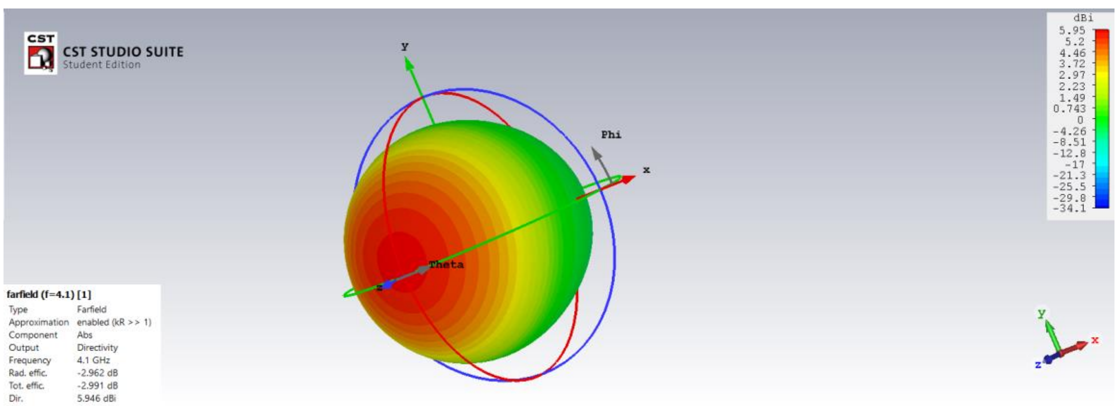


Figure 5.18: Far field radiation pattern (directivity) in 3D form for 'Antenna_1.3'

The 3D radiation pattern for the 'Antenna_1.3' at 4.1 GHz has given above is given in Fig5.18. The directivity of antenna_1.3 is 5.946dBi. It is a measure of how 'directional' an antenna's radiation pattern is. The directivity of patch antennas should be approximately 5-7dBi. Here we clearly see from the figure where there is red color it implies much more radiation. Hence the three-dimension diagram is self-explanatory. If we compare 'Antenna_1.2' and 'Antenna_1.3' the 'Antenna_1.3' is some less directional than 'Antenna_1.2' that's why the directivity of 'Antenna_1.3' is less than 'Antenna_1.2' [12].

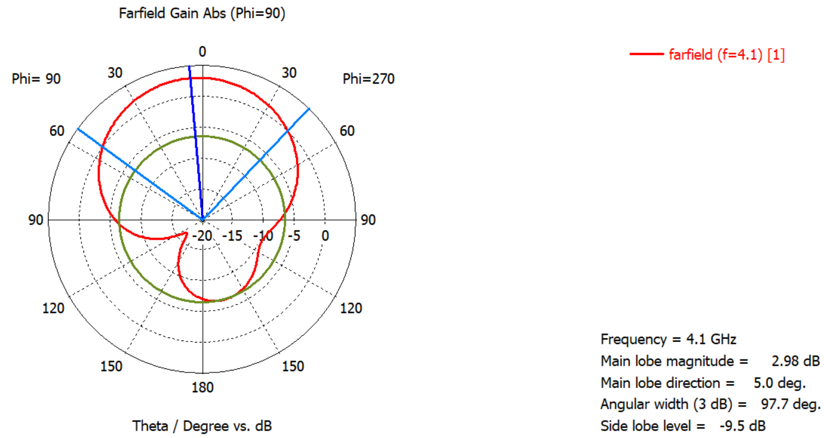


Figure 5.19: Far field radiation pattern (gain) in polar form for 'Antenna_1.3'

Far field radiation pattern (gain) in polar form for 'Antenna 1.3' is 2.98dB. The beam main lobe direction for 'Antenna_1.3' is 5 degree with beam width 97.7 degree. Main lobes are the radiation lobe containing the direction of maximum radiation. Here the side lobe is –9.5dB. We already said that controlling the width of the beam, the gain of antenna can be increased or decreased. By narrowing the beam width, the gain will increase. Antennas with wide beamwidths typically have low gain. So, if we compared 'Antenna_1.3' and 'Antenna_1.2' then we can see 'Antenna_1.3' has higher beam width and gain than 'Antenna_1.2'. But we say narrowing the beam width, the gain will increase. Here 'Antenna_1.3' has higher beam width and gain than 'Antenna_1.2'. That's happened only for changing the value of antenna parameter. So we do not compare the 'Antenna_1.2' and 'Antenna_1.3' in this case [14],[15].

Table 5: Comparison between three designed antennas (for 4.1GHz)

Antenna	Size of Antenna (mm^3)	Return Loss (dB)	VSWR	BW (%) (-10dB)	BW (MHz)	Directivity (dBi)	Gain (dB)
Antenna _1.1	$\mathbf{44.92 \times 34.54 \times 1.3 = 2017}$	-4.8	3.7	-	-	-	-
Antenna _1.2	$\mathbf{44.92 \times 34.54 \times 1.3 = 2017}$	-35.84	1.03	2.68	115.3	6.876	2.51
Antenna _1.3	$\mathbf{30.26 \times 25.07 \times 1.3 = 986.2}$	-21.8	1.177	4.324	177.3	5.946	2.98

We have designed and organized the outcome parameters of every antenna in a successive manner, and now we'll make a comparison among the three designed antennas to discover the most appropriate one.

After comparing the antennas we've found that their performance are different. Here the size of 'Antenna_1.3' is much smaller than 'Antenna_1.1' and 'Antenna_1.2' with complex slot. The bandwidth and gain of the 'Antenna_1.3' much higher than other two antenna.

If we see the overall performance of the 'Antenna_1.3' is better compared to our other designed antennas for 4.1GHz. The size of the antenna is much smaller, bandwidth and gain is high compared to our other two antennas. For those reasons, we've chosen 'Antenna_1.3 as our proposed antenna.

5.4.3 Design and Performance Analysis of Microstrip Patch Antennas With and Without Slot for 3.5GHz:

5.4.3.1 Antenna_2.1 for 3.5GHz without slot:

Table 6: Parameter list with values to design 'Antenna_2.1'

Parameter	Length (in mm)
Ground Length (Lg)	40.44
Ground Width (Wg)	52.64
Patch Length (L)	20.22
Patch Width (W)	26.32
Feed line Length (Fi)	6.16
Feed line Width (Wf)	3.13
Gap- Patch & Feed (Gpf)	1
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.6

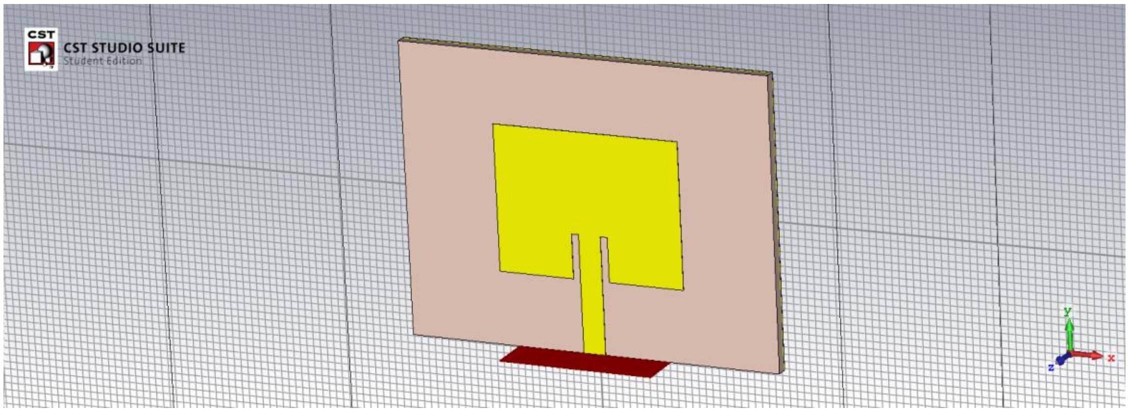


Figure 5.20: Antenna_2.1

In this case the resonant frequency will be 3.5GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.6mm is chosen as the substrate material for the patch antenna.

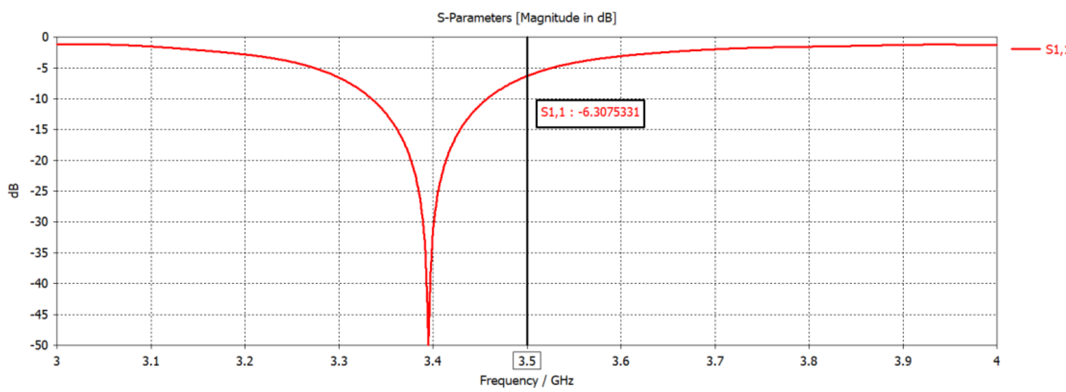


Figure 5.21: Return loss of 'Antenna_2.1'

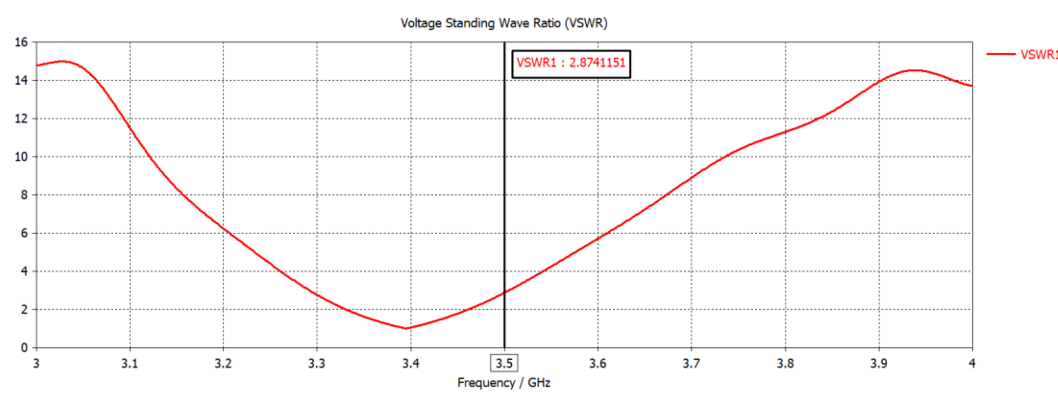


Figure 5.22: Standing wave ratio for 'Antenna_2.1'

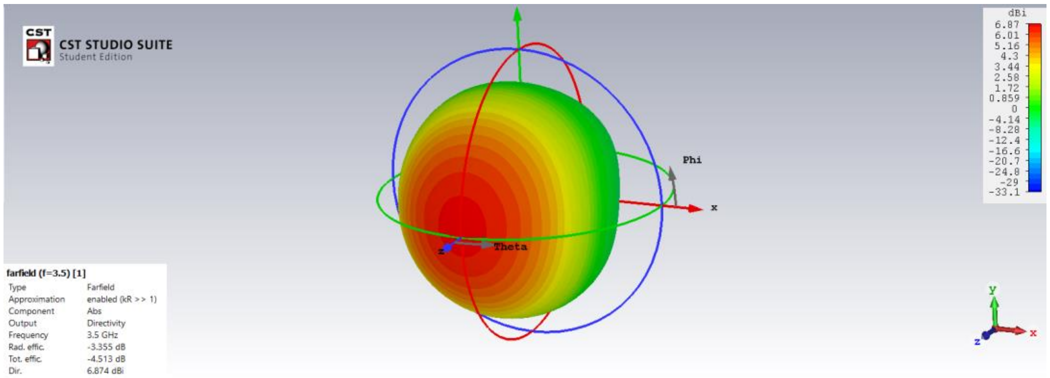


Figure 5.23: Far field radiation pattern (directivity) in 3D form for ‘Antenna_2.1’

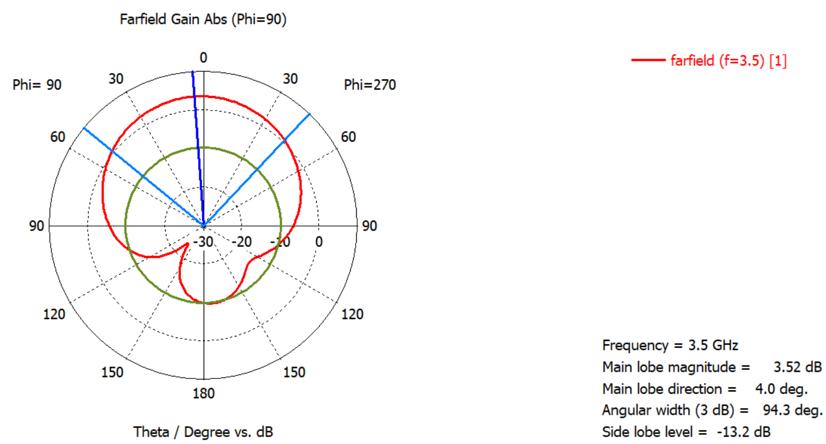


Figure 5.24: Far field radiation pattern (gain) in polar form for ‘Antenna_2.1’

S11 parameter represents how much power is reflected from the antenna, and that is known as the return loss. It is a parameter that is used to measure the power reflected by the antenna due to the mismatch of the antenna. From the return loss for ‘Antenna_2.1’ given in Fig. 5.24 shows that minimum value of return loss is achieved at 3.9GHz but at the operating frequency 3.5GHz it shows very poor result which means that most of the power was reflected from the antenna ; in other words, less power is delivered to the antenna. Here the return loss of ‘Antenna_2.1’ at 3.5GHz is -6.3dB so much less power delivered to the antenna. This not for our expected result. For better result we will slot the antenna and also change some parameter value [12].

5.4.3.2 Antenna_2.2 for 3.5GHz with complex slot:

Table 7: Parameter list with values to design 'Antenna_2.2'

Parameter	**Length (in mm)**
Ground Length (Lg)	40.44
Ground Width (Wg)	52.64
Patch Length (L)	20.22
Patch Width (W)	26.32
Feed line Length (Fi)	6.16
Feed line Width (Wf)	3.13
Gap- Patch & Feed (Gpf)	0.5
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.6

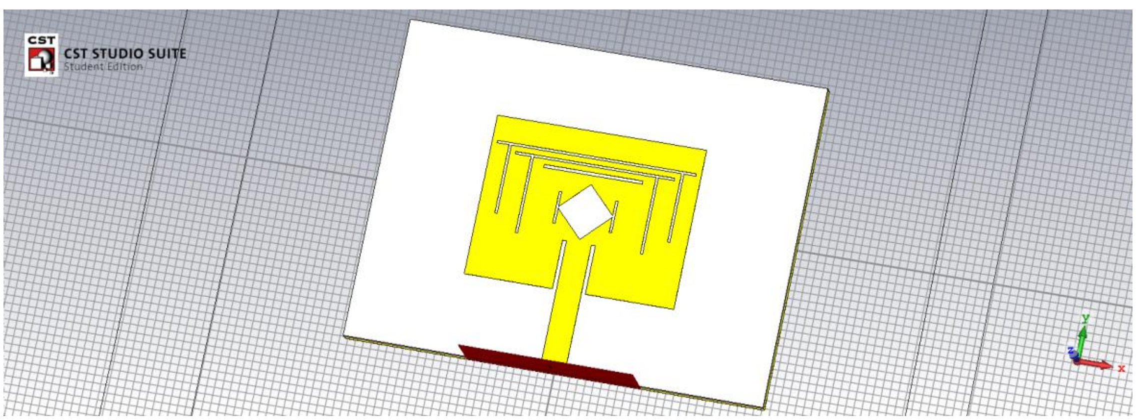


Figure 5.25: Antenna_2.2

In this case the resonant frequency will be 3.5GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.6mm is chosen as the substrate material for the patch antenna. Parameter values of 'Antenna_2.2' where only Gpf value have been changed from previous Antenna_2.1 and slots are added to shift the resonant frequency to our desired frequency of operation.

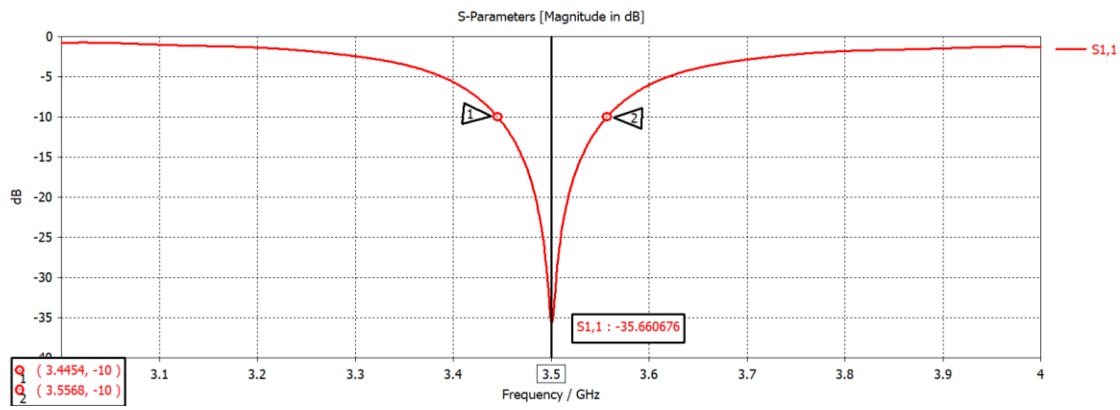


Figure 5.26: Return loss of 'Antenna_2.2'

The return loss vs frequency curve of 'Antenna_2.2' given Fig.5.26. The designed antenna resonates at 3.5 GHz. The minimum return loss at 3.5 GHz is -35.661dB, so almost all the power is delivered to the antenna and the antenna will radiate. The transmission capacity or bandwidth of the proposed patch antenna is 111.4MHz [12].

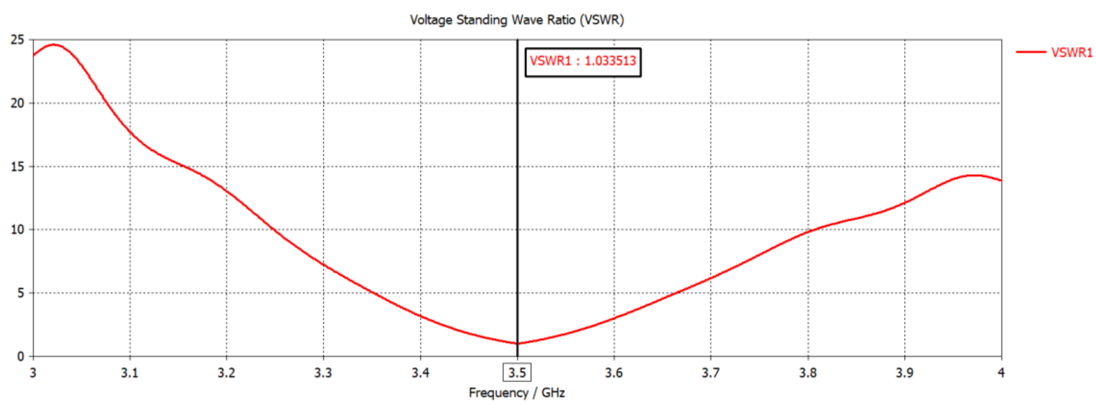


Figure 5.27: Standing wave ratio for 'Antenna_2.2'

VSWR describes how well the antenna is impedance matched to the transmission line. VSWR must lie in the rage of 1-2. The value of smaller VSWR indicate the better result. The minimum VSWR is 1. For this situation, no power is reflected from the antenna, which is perfect. The VSWR of the microstrip patch antenna is shown in Fig.5.27. From the figure we see VSWR is 1.033 at the frequency of 3.5GHz which is very close to 1. So that the antenna is performing very well according to theory and delivered almost maximum power because if VSWR is 1.2 then only 1% power reflected. For this antenna VSWR is 1.033 so maximum power delivered to the antenna [12],[13],[16].

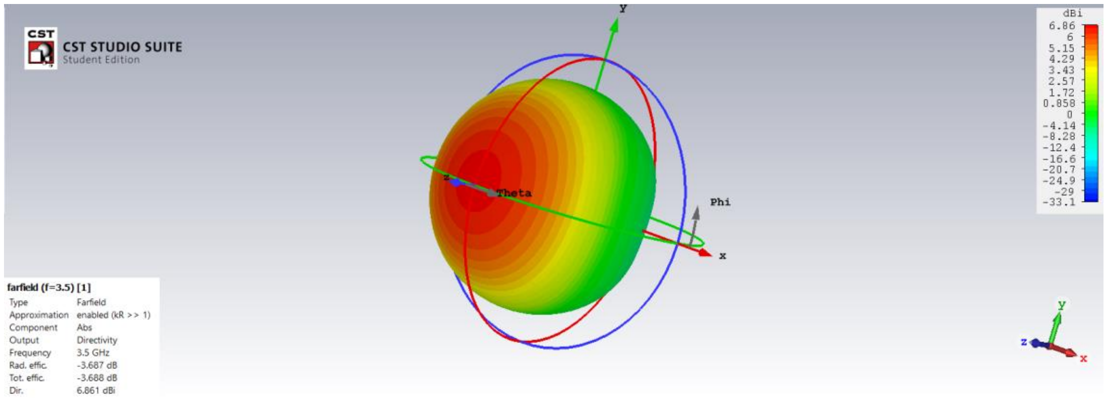


Figure 5.28: Far field radiation pattern (directivity) in 3D form for 'Antenna_2.2'

The 3D radiation pattern for the antenna_2.2 at 3.5GHz in shown in Fig.5.28. The directivity of 'Antenna_2.2' is 6.861dBi. Directivity can be understood as a direction of maximum radiation by an antenna. Our antenna radiation pattern is directional that means not equally radiated in all direction. The directivity of patch antennas is approximately 5-7dBi. Here we clearly see from the figure where there is red color the much more radiation. Hence the three dimensional diagram is self-explanatory [12].

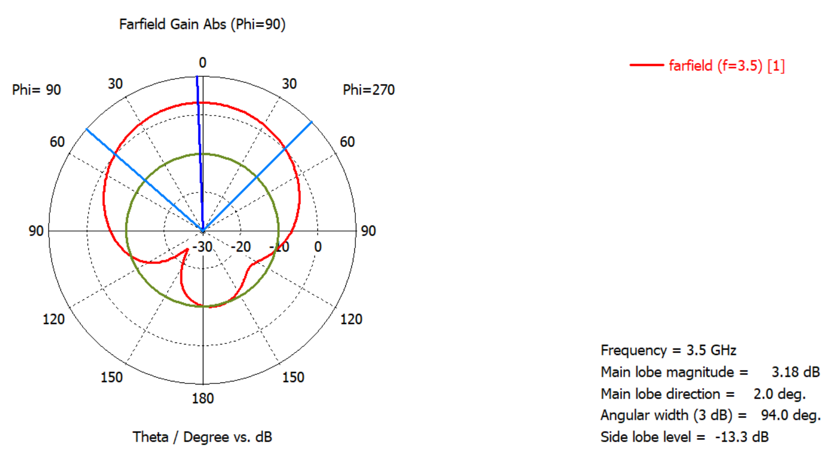


Figure 5.29: Far field radiation pattern (gain) in polar form for 'Antenna_2.2'

Far field radiation pattern (gain) in polar form for 'Antenna_2.2' is 3.18dB which is shown in Fig.5.29. The beam main lobe direction for 'Antenna_2.2' is 2 degree with beam width 94 degree. Main lobes is the radiation lobe containing the direction of maximum radiation. Here the side lobe is -13.3dB. The beam width of the antenna is a very important figure-of-merit, and it often used to as a tradeoff between it and the side lobe level. By controlling the width of the beam, the gain of antenna can be increased or decreased. By narrowing the beam width, the gain will increase and it is also creating sectors at the same time. Antennas with wide beam widths typically have low gain and antennas with narrow beam widths avail to have higher gain [14],[15].

5.4.3.3 'Antenna_2.3' for 3.5GHz with simple slot:

Table 8: Parameter list with values to design 'Antenna_2.3',

Parameter	**Length (in mm)**
Ground Length (Lg)	29.82
Ground Width (Wg)	35.92
Patch Length (L)	20.22
Patch Width (W)	26.32
Feed line Length (Fi)	6.16
Feed line Width (Wf)	3.13
Gap- Patch & Feed (Gpf)	1
Height- conductor (ht)	0.035
Height- Substrate (hs)	1.6

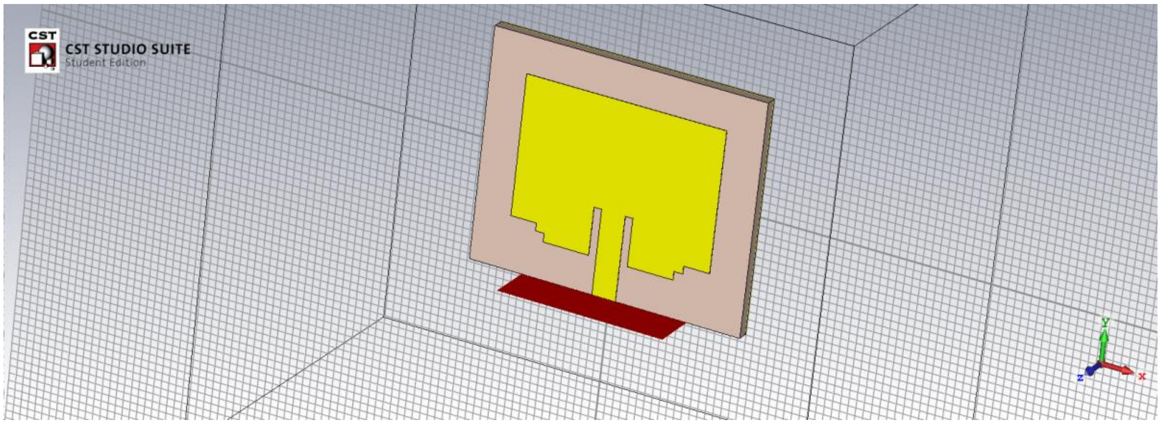


Figure 5.30: Antenna_2.3

In this case the resonant frequency will be 3.5GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (hs). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (hs) =1.6mm is chosen as the substrate material for the patch antenna. The parameter values of 'Antenna_2.3' where Wg and Lg value have been changed from previous antenna (Antenna_2.1 and Antenna_2.2) and the value of Gpf is same as Antenna_2.1. Here we also added slots in the antenna. The antenna size is much smaller than other two antennas designed for 3.5GHz.

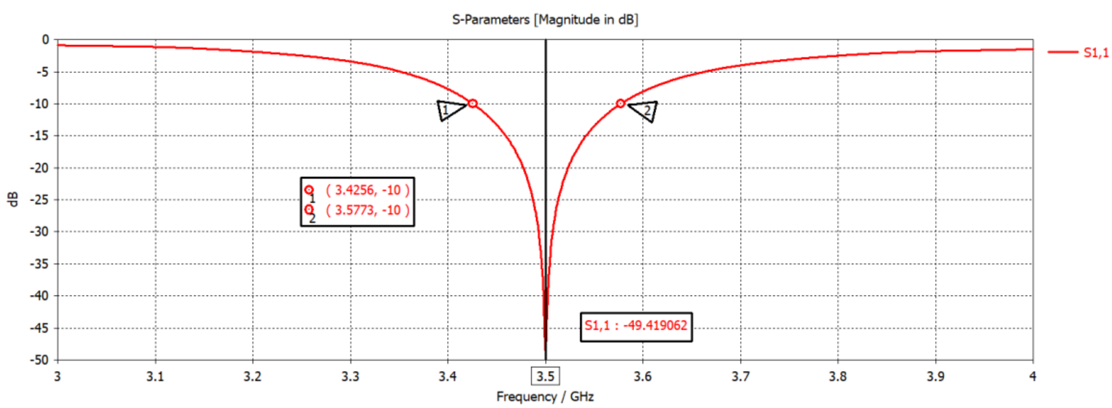


Figure 5.31: Return loss of 'Antenna_2.3'

The figure of the return loss vs frequency for 'Antenna_2.3' is given in Fig.5.31. The designed antenna resonates at 3.5 GHz. The return loss at 3.5 GHz is -49.419dB, which can be considered as a good result as it implies that almost all the power is delivered to the antenna whereas very negligible percentage of power is reflected back. The return loss versus frequency curve is shown in figure. The bandwidth of the proposed patch antenna is 151.7MHz. If we compare the return loss of ‘Antenna_2.3’ and ‘Antenna_2.2’; the bandwidth of ‘Antenna_2.3’ is increased and also the return loss is increased [12].

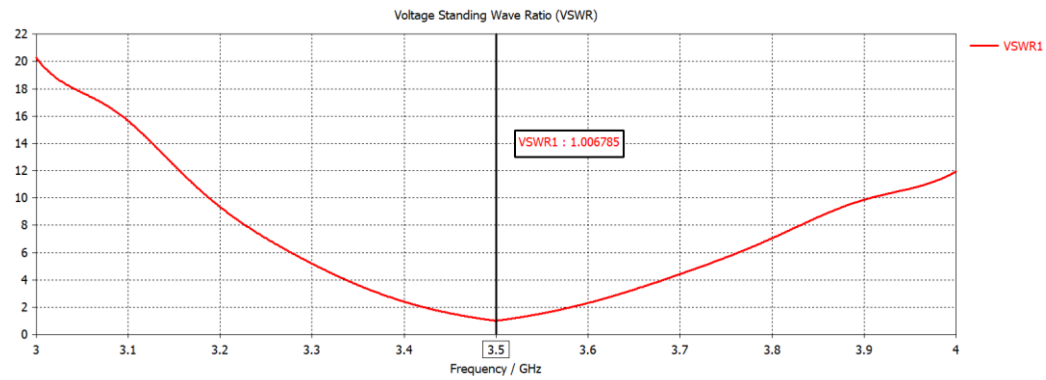


Figure 5.32: Standing wave ratio for ‘Antenna_2.3’

The VSWR of the microstrip patch antenna is shown in ‘Fig.5.32. From the figure we see VSWR is 1.006785 at the frequency of 3.5GHz which is very close to 1. So that the antenna is performing very well according to theory and delivered almost maximum power. If we compare ‘Antenna_2.2’ and ‘Antenna_2.3’ we will see the small difference between them. The value of VSWR for ‘Antenna_2.3’ is lower than ‘Antenna_2.2’ because VSWR is directly related to return loss value. Here the return loss value for ‘Antenna_2.3’ is much better than ‘Antenna_2.2’. But both antenna has almost 0% reflection and 100% power transmitted to the antenna [12],[13],[16].

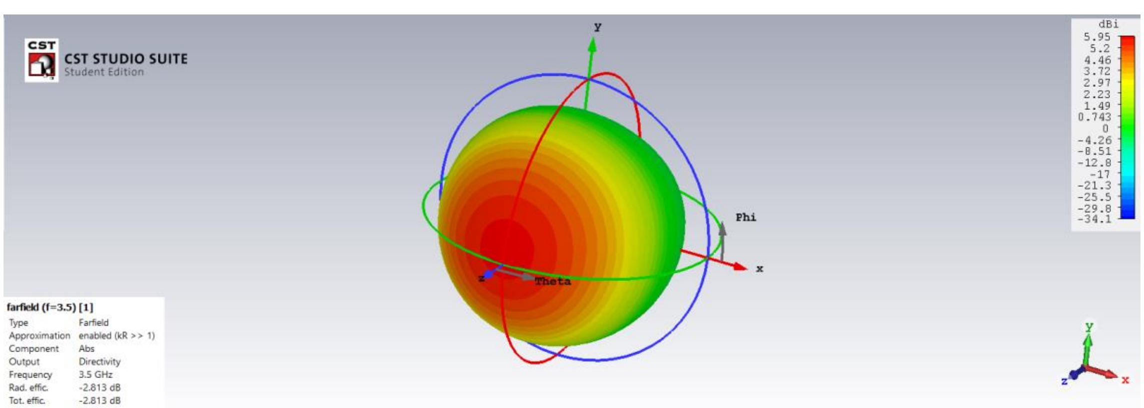


Figure 5.33: Far field radiation pattern (directivity) in 3D form for ‘Antenna_2.3’

The 3D radiation pattern for the ‘Antenna_2.3’ at 3.5 GHz is given in Fig.5.33. The directivity of ‘Antenna_2.3’ is 5.946dBi. It is a measure of how 'directional' an antenna's radiation pattern is. The directivity of patch antennas is approximately 5-7dBi. Here we clearly see from the figure where there is red color the much more radiation. Hence the three-dimensional diagram is self-explanatory. If we compare ‘Antenna_2.2’ and ‘Antenna_2.3’ the ‘Antenna_2.3’ is some less directional than ‘Antenna_2.2’ that’s why the directivity of ‘Antenna_2.3’ is less than ‘Antenna_2.2’ [12].

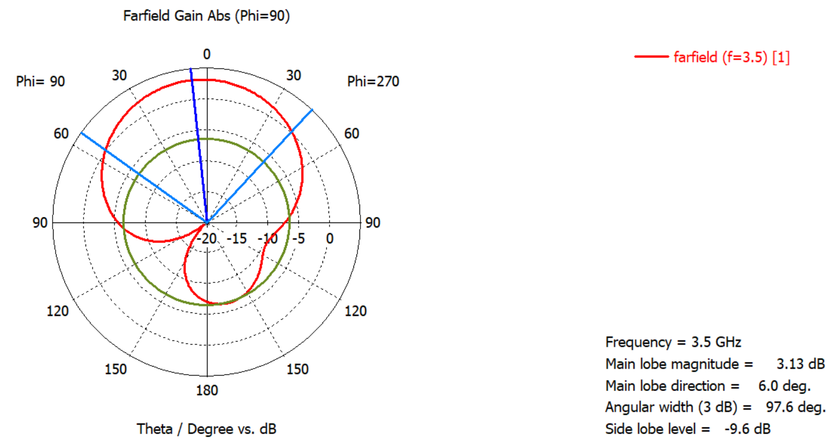


Figure 5.34: Far field radiation pattern (gain) in polar form for ‘Antenna_2.3’

Far field radiation pattern (gain) in polar form for ‘Antenna 2.3’ is 3.13dB which is shown in Fig.5.34. The beam main lobe direction for ‘Antenna_2.3’ is 6 degree with beam width 97.6 degree. Main lobes are the radiation lobe containing the direction of maximum radiation. Here the side lobe is –9.6dB. We already said that controlling the width of the beam, the gain of antenna can be increased or decreased. By narrowing the beam width, the gain will increase. Antennas with wide beamwidths typically have low gain. If we compared the ‘Antenna_2.2’ and ‘Antenna_2.3’ gain of these two antennas is almost same. ‘Antenna_2.3’ has some less gain then ‘Antenna_2.2’ but the size of ‘Antenna_2.3’ much less than ‘Antenna_2.2’ for changing some parameter value [14],[15].

Table 9: Comparison between three designed antennas (for 3.5GHz)

Antenna	Size of Antenna (mm^3)	Return Loss (dB)	VSWR	BW (%) (-10dB)	BW (MHz)	Directivity (dBi)	Gain (dB)
Antenna _2.1	$\mathbf{52.64 \times 40.44 \times 1.6 = 3406}$	-6.31	2.87	-	-	-	-
Antenna _2.2	$\mathbf{52.64 \times 40.44 \times 1.6 = 3406}$	-35.66	1.03	3.183	111.4	6.861	3.18
Antenna _2.3	$\mathbf{35.92 \times 29.82 \times 1.6 = 1713.8}$	-49.42	1.006	4.33	151.7	5.946	3.13

We've designed and organized the simulation result of every antenna for 3.5GHz in a successive order, and now we'll make a comparison among the three designed antennas to discover the most appropriate one.

After comparing the antennas we've found that their performance are different. Here the size of 'Antenna_2.3' is much smaller than 'Antenna_2.1' and 'Antenna_2.2' with complex slot. The return loss is minimum, bandwidth is high, VSWR almost equal to 1 of the 'Antenna_2.3'. Gain of the antenna is few less then 'Antenna_2.2' but if we see the overall performance of the 'Antenna_2.3', so we can say 'Antenna_2.3' is better compared to our other designed antennas for 3.5GHz. For those reasons, we've chosen 'Antenna_2.3 as our proposed antenna.

5.5 Comparison to Other similar Antenna

Table 10: Comparison of our proposed antenna with others designed antenna (For 4.1GHz).

SL	Size of Antenna (mm^3)	Return Loss (dB)	BW (MHz)	Operating freq. (GHz)	Reference
1	30.26×25.07×1.3=986.2	-21.8	177.3	4.1	Proposed antenna
	$32.84 \times 26.4 \times 1.574 = 1364$	-14	105	4.2	Sukhmandeep[18]
2	$31.86 \times 26.55 \times 1.6 = 1353.4$	-19.54	43.3	4.1	Houda , Khaoula, et al [19]
3	$44 \times 30.2 \times 1.6 = 2126.08$	-12.32	58	4.3	Ashish, Bimal et al [20]
4	$46.9 \times 38.01 \times 1.4 = 2495.73$	-27.5	115	4.1	Dobir, Sobaha, et al [21]

We compared ‘Antenna_1.3’ with similar profile antenna designing published in international journals or other. Our proposed antenna have much higher bandwidth with good return loss value. It can radiate quite efficiently at 4.1GHz band as it has a good flexibility in bandwidth. Our antenna has much smaller size compare to other antenna size which we are show in Table10. For those reasons, we will say our proposed antenna quite good compare to other antenna.

Table 11: Comparison of our proposed antenna with others designed antenna (for 3.5GHz)

SL	Size of Antenna (mm^3)	Return Loss (dB)	BW (MHz)	Operating freq. (GHz)	Reference
1	35.92×29.82×1.6=1713.8	-49.42	151.7	3.5	Proposed antenna
2	$42.85 \times 42.85 \times 1.6 = 2937.8$	-10.38	36	3.5	Ehab Esam , et al [22]
3	$42 \times 40 \times 1.6 = 2688$	-42.87	96	3.5	Ehab Esam et al [22]
4	$35.212 \times 29.2 \times 1.6 = 1645.1$	-19	20	3.55	Ashish, Nites et al [23]
5	38×29.×1.6=1763.2	-25.2	80	3.5	Mr. Prasanna et al [24]
6	62.97×78.67×1.245=6167	-37.5	50	3.5	Alhaji Osman et al [25]

We compared ‘Antenna_2.3’ with similar profile antenna designing published in international journals or other. Our proposed antenna have much higher bandwidth with good return loss value. It can radiate quite efficiently at 3.5GHz band. Our antenna has much smaller size compare to other antenna size which we are show in Table11 and this is better than other designed antenna compare to similar profile antenna designing published in international journals or other. Also one comparison to E-Shaped Microstrip Patch Antenna design for WiMAX [17]. The antenna is design for 3.5GHz resonant frequency and use FR4 substrate with thickness of 3.2mm. The return loss is -33.913dB directivity of the antenna is 6.86368 and the gain of the antenna is 4.55935. Our proposed antenna is designed for also 3.5GHz and we use FR4 substrate with thickness of only 1.6 mm. and the return loss, BW, VSWR, directivity and gain for ‘Antenna_2.3’ is -49.419dB, 151.7MHz, 1.006, 5.946dBi and 3.13dB respectively. Here the bandwidth and return loss of our antenna is higher than E shaped antenna. If we compare the thickness our gain is much better than E shape antenna because higher the thickness better the gain. So proposed antenna has much reduced the size with better performance compared to this E shape antenna. For above reasons, we will say our proposed antenna is quite good compare to similar profile antenna designing published in international journals or other.

Chapter 6 : Conclusion & Future Work

6.1 Conclusion:

In this work, rectangular microstrip patch antennas have been designed and simulated using CST Microwave Studio which is a commercially available high performance EM field simulator. We have successfully designed several microstrip patch antennas using FR-4 as substrate material with $\varepsilon_r = 4.3$, annealed copper for ground and patch for the narrow band microstrip patch antenna for operating frequencies 4.1GHz and 3.5GHz for different wireless applications. Here we used inset feeding techniques as it is easier to fabricate compared to other feeding techniques and this feed can be provided anywhere inside the patch. The performances of the designed antennas are investigated in terms of return loss (S11), bandwidth calculated at -10dB reflection coefficient, radiation pattern in 3D and polar form, directivity, and gain. Various structures like microstrip patch antenna without slots, with complex slots and simple slots have been designed. It has been seen that a properly slotted antenna can outperform a simple patch antenna without slots. It has been observed that adding multiple slots in the patch, we can achieve resonance at our desired frequency and therefore can change the return loss, antenna gain, and directivity to achieve our expected result. While optimizing the antenna design parameters to achieve better results, some parameters were found to affect the antenna performance. They are the relative permittivity of the dielectric material used as substrate under the patch, the width (Wf) of the microstrip feed line, the position of the slot on the patch (it is seen that slight change in the location of the slot produces significant change in the result), and height of the substrate (hs). It is found that increasing or decreasing height of the substrate the bandwidth, gain, radiations pattern also increase or decrease.

The proposed antenna for 4.1GHz resonated at a return loss of -21.8dB, giving a bandwidth of 177.3MHz which is 4.324% at -10dB, VSWR of 1.177, 5.946dBi directivity and 2.98dB gain. For 3.5GHz the proposed antenna achieved a minimum return loss of -49.42dB, bandwidth obtained about 151.7MHz which is 4.33% at -10dB, VSWR of 1.006, 5.95dBi directivity and 3.13dB gain. The return loss values are way below -10dB which suggest there is very good matching. From the achieved values of VSWR, we can see that they are very close to 1, which indicate that our antenna was very closely matched with the 50 Ohm transmission line. The directivity of proposed antennas were maintained to be greater than 5dBi at the resonant frequencies. Overall we can say that the results achieved are quite satisfactory.

6.2 Future work and modification:

The proposed Microstrip patch antenna have small value of gain and design for naroow band application. In modern telecommunication system use Wideband and ultra-wideband patch antenna for high speed communications so now we can developed this antenna or any type of similar range of antenna. In many way we can improved the antenna.

1. The radiation pattern, directivity, gain and efficiency can be improved by using low relative permittivity of the dielectric material.
2. Increase the substrate height for increase the bandwidth.
3. Control the Beam width for increase the bandwidth. If the beam width is narrow then bandwidth is high.
4. FR4 as substrate, you can never get a high gain. FR4 can produce gain of 3-5dBi. So we can use RT/Duroid 5880, Arlon Di 522 etc.
5. Multiple patch antennas on the same substrate can be used to make high gain array antennas. An antenna array can achieve higher gain (directivity), which is a narrower beam of radio waves, than could be achieved by a single element. So, Arrays can be used to achieve higher gain.
6. We can use any shaped of slots to change the directivity and others parameters.

So, our proposed antenna design can be further improve in terms of basic parameters such as type of substrate, dielectric constant and the thickness of the substrate.

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